ELEMENTARY PHYSICS

AVERY

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BY

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PREFACE.

THIS book has been prepared because of a belief that it was needed and would be welcomed. More specifically, the book is an attempt to meet the wants of schools that cannot give to the study the time required for the completion of the author's larger work, and yet demand a book that is scientifically accurate and "up to date." No effort has been spared by author or publishers to make it worthy of the place it is intended to fill. Especial care has been taken to provide simple *teaching* experiments that do not require expensive apparatus, and a good supply of well-adapted laboratory exercises. The author trusts that these efforts will meet with the approval of those who use the book.

It is not expected that every pupil will solve every problem or perform all of the laboratory work indicated in the "Exercises." The pupil should do as much as possible, but the good judgment of the wise teacher must be called upon to determine how much, and to select just what is best adapted to the needs and capacity of each member of his class. No author can make a comfortable Procrustean bedstead, and there can be no satisfactory substitute for the living teacher.

Much of the matter in this book is wholly new, and some of the apparatus described was designed expressly for it. Especial acknowledgment is due to Miss Emma Hogan, assistant principal of the Woodland Hills Avenue School of Cleveland, to Mrs. Alton H. Smith, and to Mrs. Elroy M. Avery, for aid in the revision of copy.

Teachers using this book are advised to ask the Ziegler Electric Company, 141 Franklin Street, Boston, Mass., for a copy of their catalogue of scientific apparatus.

The author will be glad to receive suggestions from teachers who use this book, and to answer any inquiries that they may make. He may be addressed at Cleveland, Ohio.

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CHAPTER I.

MATTER.

I. THE STRUCTURE, DIVISIONS, AND CHANGES OF MATTER.—FORCE, ETC.

1. Physics, or Natural Philosophy, is the science of matter and energy. Science is classified knowledge. Matter is anything that "takes up room." Energy is the power of doing work. We shall understand the meaning of these words better as we go on.

(*a*) *Substances* are the different kinds of matter, as water, wood, and silver. A *body* is any separate portion of matter, as a book, a table, or a star. Matter is indestructible.

Structure of Matter.

Experiment 1.—Heat the mercury in the bulb of a common thermometer. The bulb remains full, but the liquid rises in the tube. There seems to be more mercury than there was before. How can this be? There must be a greater number of particles, the particles must be larger, or *they must be further apart.*

Experiment 2.—Make a common goose-quill pop-gun. Notice that, when you use it, the air confined between the two wads is made to occupy about half the space it did before. The air particles are reduced in size or in number, or are crowded together more closely. *Perhaps the matter of which a body is made does not actually fill all the space that the body seems to occupy.*

2. Structure of Matter.—Many facts indicate that matter is not continuous; that any part of it that we can perceive is a group of very small particles; that no two of

these are in actual contact; and that the minute particles of each group are held together by certain forces.

3. Divisions of Matter. — Matter appears to us as masses. Masses are made up of molecules, and, in nearly every case, molecules are made up of atoms.

4. An Atom is the smallest quantity of matter that can enter into chemical combination, thus forming a molecule. It is the chemical unit of matter, and is considered indivisible. There are more than seventy kinds of atoms now known. The study of atoms belongs to chemistry rather than to physics.

5. A Molecule *is a quantity of matter so small that it cannot be divided without changing its nature.* It is the physical unit of matter, and can be divided only by a chemical process. Molecules are believed to be in ceaseless motion.

(*a*) If a drop of water could be magnified until it appeared to be as large as the earth on which we live, each molecule in the drop thus magnified would still look smaller than a base-ball. Even in dense solids, molecules are separated by spaces that are large as compared to their own size. It is probable that the distance between two molecules is several times the diameter of a molecule. Some molecules are very complex. The common sugar molecule contains forty-five atoms of three kinds. There are innumerable kinds of molecules. The nature of the molecule determines the nature of the substance.

6. A Mass *is a group of molecules.*

7. Forms of Motion. — It is probable that each of these three divisions of matter has its own form or mode of motion. *The motion of a mass is often called molar or mechanical motion.* The motion of a bullet is an example. *The motion of the molecules in a mass constitutes heat.* If a bullet strikes a target, the shock that destroys the molar motion of the bullet increases the vibration of the mole-

cules of which the bullet is composed. These molecular vibrations constitute heat. The motion of atoms within the molecule has not been proved.

(*a*) Fancy a million flies surrounded by a shell. If each fly represents a molecule, the contents of the shell represent a mass. Imagine this shell to be thrown through the air. The motion of the shell represents molar motion. As the shell is moving through the air, the flies are moving slowly among themselves within the shell. This motion of the flies represents molecular motion, and is a very different thing from the motion of the shell. When the shell strikes the ground, the molar motion is destroyed, but the molecular motions are increased, for the flies are set in much more rapid motion by the shock. This is just about what happens when a bullet is fired against a target.

8. Physical and Chemical Changes. — Any change that alters the constitution of the molecule, and thus affects the identity of the substance, is a *chemical change*. The burning of a candle or the rusting of iron is a chemical change. Any change in matter that does not alter the constitution of the molecule is a *physical change*. Heating or magnetizing a piece of iron is a physical change; the iron remains iron.

9. Phenomena, etc. — Any directly observed change in matter is a *phenomenon*. A supposition (or scientific guess) advanced in explanation of phenomena is an *hypothesis*. The value of an hypothesis increases with the variety of the phenomena for which it offers an exclusive explanation. As this variety increases, the hypothesis rises to the rank of a *theory*. When the theory has acquired so high a degree of probability that it is accepted by the judicious as an established truth, i.e., when it is easier for men to believe it than to doubt it, it becomes a *law*, e.g., the law of gravitation. "Law means a rule which we have always found to hold good, and which we expect always will hold good."

10. Force. — *Force signifies the immediate cause that produces, or tends to produce, a change in the velocity or the direction of motion of a body;* i.e., a push or a pull.

EXERCISES.

1. What is science?
2. What is matter?
3. What is energy?
4. What is physics?
5. What is a substance?
6. What is a body?
7. Do you think that matter is continuous or not, and why?
8. Define the several divisions of matter.
9. State the difference between mechanical and molecular motion.
10. Give an original illustration of a physical and of a chemical change.
11. What is the difference between an hypothesis and a theory?
12. What is a physical phenomenon?

II. THE PROPERTIES OF MATTER.

11. Properties of Matter. — *Any quality that belongs to matter, or is characteristic of it, is called a property of matter.* Any property that can be shown without a chemical change is a physical property.

12. Extension *is that property of matter by virtue of which it occupies space.* It has reference to length, breadth, and thickness.

13. Measurement of Extension. — There are two linear units in use in this country, — the English yard and the international meter. From these are derived units of area and of volume.

(*a*) It is assumed that the pupil is familiar with the units of weights and measures of both the English and the metric systems.

The scientific unit of length is the centimeter, the one-hundredth part of the meter. See Fig. 1.

EXERCISES.

1. With a yardstick, measure the length of your class-room.

2. Compute the equivalent of that length in meters and decimals thereof.

3. With a meter stick, measure the length of your class-room, and compare the result with that obtained by computation.

4. With a meter stick, measure the door of your class-room, and make an outline sketch thereof, using the scale of 1:20.

5. With a yardstick, measure the width of your class-room. Draw a ground plan of the room, using the scale of one inch to the yard.

6. Make the necessary measurements and compute the capacity of the room (*a*) in cubic feet, (*b*) in cubic meters, (*c*) in gallons, (*d*) in liters.

7. With the meter stick, measure the length of this leaf of your book. Place the stick on its edge so as to bring the graduation as close as possible to the object to be measured. Bring, not the end of the rod, but one of the centimeter marks, even with one end of the leaf, and from the stick read the length of the page accurately to 0.1 mm. You can divide the smallest division on the scale into tenths by the eye.

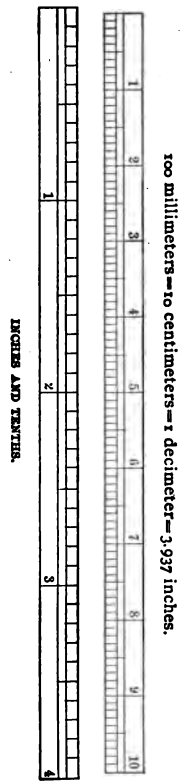

FIG. 1.

8. Make two fine marks with a sharp knife on a table-top or other board, as far apart as is convenient, the distance being more than a meter. Measure as accurately as possible the distance between the marks, estimating fractions of millimeters to tenths, and expressing the results in meters. Do this ten times. Measure the same distance in inches, estimating fractions of the smallest division on the scale to tenths. Express these results in inches and decimals of an inch. Do this ten times. Divide the average number of inches by the average number of meters; the quotient will be the number of inches in a meter. Express in millimeters the measures that you took

in meters, and divide the average number of millimeters by the average number of inches; the quotient will be the number of millimeters in an inch.

FIG. 2.

9. With the graduate, i.e., a glass vessel graduated to cubic centimeters, measure 250 cu. cm. of water and pour it into the liter measure. See how often you can repeat the work without overflowing the measure. It will require careful attention to tell just when the water-level reaches the required mark. The liquid climbs up the sides of the glass, so that it is difficult to tell where the water-level really is. The eye of the observer should be placed on the level of the required mark on the graduate.

10. Compute the number of cubic centimeters in a quart. Test your result by the actual measurement of water or of dry sand.

14. Mass and Weight. — The mass of a body is its quantity of matter. *The weight of a body is, in general terms, the measure of the earth's attraction for it.* The mass of a given body is constant; its weight is not.

(*a*) If the given body could be carried to the moon, its weight there would be the measure of the attraction existing between the body and the moon. The mass of the given body would be the same as it was on the earth, but its weight would be less.

(*b*) The word "mass" is here used with a meaning different from that employed in § 6. This double use of the word is unfortunate.

15. Units of Mass and Weight. — The English unit of mass is the quantity of matter contained in the avoirdupois pound. The international unit of mass is the kilogram. For many scientific uses, this unit is too large; and the gram, which is the one-thousandth part of the kilogram, is generally used. The units of weight measure the attractions of the earth for the units of mass, and receive the same names. Under like conditions, a comparison of weights may be substituted for a comparison of masses, since at any one place the weight varies as the mass.

(*a*) The mass of a gram was intended to be, and is very nearly, equal to the quantity of matter in one cubic centimeter of distilled water at the temperature of 4° C.

EXERCISES.

1. Provide an iron ball an inch or two in diameter, a base-ball, and a croquet-ball. Measure the mass of each of the three balls in English units.

2. Determine, in international units, the mass of a nickel 5-cent coin; of the iron ball.

3. Place a meter stick on the table, and by its edge place two rectangular wooden blocks (crayon boxes will answer for rough work). Place the croquet-ball between the blocks. Move the blocks as near each other as possible with the ball between them, keeping one face of each block in contact with the straight edge of the meter stick. What is the diameter of the ball?

4. (*a*) In similar manner, measure the diameter of the base-ball. (*b*) On paper, draw a circle of that diameter. (*c*) With a sharp penknife, cut out the circle; pass the base-ball through the hole.

5. (*a*) Compute the number of cubic centimeters of water that will weigh as much as the iron ball. (See Exercise 2.) (*b*) Place the iron ball in a tumbler or beaker filled with water; catch and measure in the graduate the water that runs over. (*c*) From this measure, determine the volume (cubic centimeters) of the ball.

6. If alcohol is 0.8 times as heavy as water, how much will 1,250 cu. cm. of alcohol weigh?

7. Using international units, weigh a dry, clean bottle. Fill the bottle with cold water, wipe its outside surface dry, and weigh the filled bottle. From the weight of the water, determine the capacity of the bottle. Test the result by measurement with the graduate.

8. What part of a liter of water is 250 grams of water?

9. If sulphuric acid is 1.8 times as heavy as water, what weight of the acid will a liter flask contain?

10. Weigh each of five bullets at least three times. For each bullet take the average of the several weighings as the true weight. Combine these several averages to find the weight of the average bullet. Count the bullets in a cupful. Multiply the weight of the average bullet by the number of bullets, and compare the result with the mass of all the bullets as determined by weighing them together.

Inertia.

Experiment 3.—Upon the tip of the forefinger of the left hand, place a common calling-card. Upon this card, and directly over the finger, place a cent. With the nail of the middle finger of the right hand let a sudden blow or "snap" be given to the card. A few trials will enable you to perform the experiment so as to *drive the card away, and leave the coin* resting upon the finger. Repeat the experiment with the variation of a bullet for the cent, and the open top of a bottle for the finger-tip.

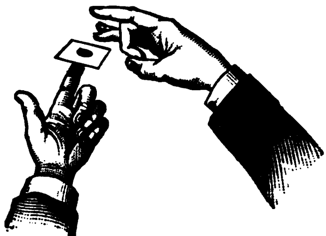

Fig. 3.

Experiment 4.—Suspend an iron ball weighing at least 10 pounds by a long, stout string from a firm support. Safety-valve weights may be bought for a few cents a pound, and answer admirably for many such purposes. Tie a string strong enough to carry a weight of several pounds to the ball, and with sudden motion pull the ball horizontally. If the pull is sudden enough, *the string will break* without giving much motion to the ball. Replace the stout string by a thread, and by a series of gentle, well-timed pulls, set the ball swinging. When it is in rapid motion, try to stop that motion by a single pull on the thread. It will be seen that *the ball can go ahead as well as hang back.*

16. Inertia *signifies the tendency of matter at rest to remain at rest, and of matter in motion to move with uniform velocity in a straight line.*

Porosity.

Experiment 5.—Pour 30 cu. cm. of water into a long test-tube. Carefully add 20 cu. cm. of strong alcohol, holding the tube so that the latter may run down its side and rest upon the water without mixing with it. Gently bring the tube into a vertical position, mark the height of the liquid in the tube, close the mouth of the tube with the thumb, and thoroughly shake the two liquids together. Notice again the height of the liquid contents of the tube. It looks as if some of the water and some of the alcohol had been forced into the same space, in spite of the impenetrability of matter.

Experiment 6.—Fill a glass tumbler with large shot or peas, and then see how much well-dried sand or salt you can add. *Perhaps what happens here is analogous to what happened in Experiment 5.*

17. Porosity *is that property of matter by virtue of which spaces exist between the molecules.* A body does not completely fill the space it seems to occupy. As a result of this, it sometimes seems as if two bodies were in the same space at the same time. The molecules of one body fit into the spaces between the molecules of the other body.

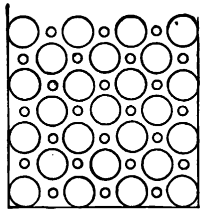

FIG. 4.

(*a*) When iron is heated, the molecules are pushed further apart, the pores are enlarged, and we say that the iron has expanded. When a piece of iron or lead is hammered, it is made smaller, because the molecules are forced nearer together, thus reducing the size of the pores. Cavities or cells, like those of bread or sponge, are not properly called pores.

18. Strain and Stress.—*Any change in the shape or size or volume of a solid is called a strain.* Thus, if a mass of metal becomes compressed, or bent, or twisted, or distorted in any way, it is said to experience a strain. *The force that produces a strain is called a stress.*

Elasticity.

Experiment 7.—Squeeze a rubber ball. Stretch a rubber band. Stretch a spiral spring. Bend a thin strip of steel, wood, or whalebone. In each case *the volume or form is restored to its initial condition when the distorting force ceases to act.*

19. Elasticity *is that property of matter by virtue of which bodies resume their original form or size when that form or size has been changed by any external force.* There is an elasticity of volume, and an elasticity of form or figure. The former is peculiarly a property of gases and liquids; the latter, of solids.

(*a*) The elasticity of a body may be developed by pressure, by pulling, by bending, or by twisting.

Molecular Attraction.

Experiment 8. — Dip a finger into water. Upon removing it, notice that it is wet, that water adheres to it. Hold the finger pointing downward, and notice that a drop of water gathers at the finger-tip. That drop is composed of many particles that cling together, or cohere. *Something makes the water particles cling to each other and to the finger*, in spite of the force of gravity.

Experiment 9. — Cut a lead bullet so as to present two flat, clean surfaces. Press the two parts together with a slight twisting motion. *They will cling together.*

Experiment 10. — Take a sheet of gold leaf in your fingers, and try to pick the metal off with the fingers of the other hand. *Some of the gold will stick to your fingers.*

20. Cohesion and Adhesion. — *Cohesion is the force that holds together like molecules; adhesion is the force that holds together unlike molecules.*

(*a*) This force acts only at insensible (molecular) distances. Let the parts of a body be separated by a sensible distance, and we say that the body is broken. If the molecules of the parts can again be brought within molecular distance of each other, cohesion will again act, and hold them there. This may be done by simple pressure, as in the cases of wax, freshly cut lead, broken ice, and many powders; it may be done by welding or melting, as in the case of iron.

21. Hardness *is that property of matter by virtue of which some bodies resist any attempt to force a passage between their particles.* The relative hardness of two substances is determined by finding out which of them will scratch the other; e.g., we know that glass is harder than copper because it will scratch copper.

Tenacity.

Experiment 11. — Cut several strips of manilla paper about 5 by 25 cm. Turn each end of each strip over, and fasten the edges

with glue so as to make a good hem at each end. In the loop at one end of the paper strip insert a stout rod the length of which exceeds the width of the paper strip. Fasten this rod by a stout string or wire bail to a nail in a board or table-top. Similarly fasten the other end of the strip to the hook of a good spring-balance, held as shown in Fig. 5. Pull steadily with the balance and in a line with its length, so as to avoid, as far as possible, all friction of the sliding bar to which the hook is attached. Watch the index of the balance all the time, looking directly down upon it so as to avoid the error of parallax. Continue to pull until the paper breaks. Be careful that the recoil of the hook does not injure your hands. Repeat the experiment

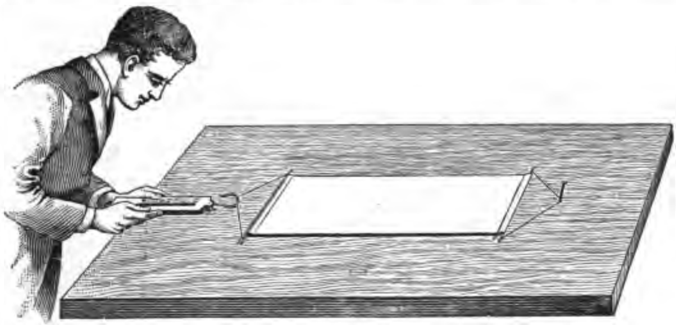

FIG. 5.

with several similar strips, recording after each test the maximum reading of the index. If the index does not rest over the zero mark when the balance is in a horizontal position, the proper correction should be made for each reading taken. *The average of these several readings will be a fair expression of the strength of the paper.* Make a similar series of tests with similar strips of paper twice as wide. Compare the two average results. Compute the strength of a strip 2.2 cm. wide, and experimentally verify the result.

22. Tenacity *is that property of matter by virtue of which some bodies resist a force tending to pull their particles asunder.*

(*a*) Like hardness and other characteristic properties of matter, tenacity is a variety of cohesion. For any given material, it has been

found that *tenacity is proportional to area of cross-section;* e.g., a rod with a sectional area of a square inch will carry twice as great a load as a rod of the same material with a sectional area of a half square inch; a rod 10 cm. in diameter will carry four times as great a load as a similar rod 5 cm. in diameter.

EXERCISES.

1. Name some property of matter not mentioned in the text.

2. Can any substance exist without extension?

3. How many inches are there in a meter?

4. Which is the larger, a liter or a cubic decimeter?

5. Which is variable, the mass of a given body or its weight? Why?

6. What is the relation between a cubic centimeter and a milliliter?

7. What is a gram?

8. Can an atom be destroyed?

9. Which is the natural condition of matter, rest or motion?

10. On what property of matter does compressibility depend?

11. If you thrust a knitting-needle into a mass of dough, is the hole thus made a pore? What is a pore?

12. It may be said that strain and stress are related as cause and effect. Which is cause, and which is effect?

13. If you have made a series of careful measurements, each of which differs a little from all the others, what is the safest one to adopt?

14. What is the length of a full line as printed in this book? Place the graduated edge (not the side) of the decimeter rule on the paper, with some plainly visible mark, as 0.5 or 1 cm. (not the end of the rule), at one end of the printed line. Always use a rule in this way for accurate measurements.

15. Tightly pinch the leaves of this book (inside the covers) between two small blocks that come flush with them at the top. Remove some of the leaves so that those that remain make a layer just 1 cm. thick. Count the leaves, and compute in decimals of a millimeter the thickness of an average leaf of this book.

16. Determine the gauge numbers of four pieces of wire. Use the notches around the edge of the steel plate (Fig. 6), and not the larger circular openings at the inner end of the notches. Introduce the wire into the slit which admits it with a very slight pressure, and

note the number corresponding to that slit. Be sure that the wire is not rusty, dirty, or bruised at the point where it is gauged. It is convenient to buy such wire wound on spools.

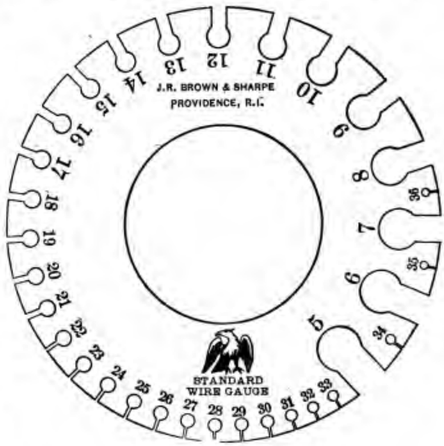

FIG. 6.

17. Wind 25 turns of No. 30 annealed wire around a cylinder an inch or more in diameter, being careful that the successive turns are as close as possible to each other. Measure the total width of the wire band on the cylinder, and compute the diameter of No. 30 wire. Compare your result with the table given in the appendix.

18. With the outside calipers, measure the diameter of the iron ball used in Exercise 1 on page 13. Compare the result then obtained and recorded in your notebook with that now found.

FIG. 7.

19. Measure the diameter and length of a small cylinder. If, by measuring the rod at short intervals with the calipers, you find that its diameter is not uniform, use the average of your several measurements. (*a*) Compute the surface area of the cylinder. (*b*) Compute the volume of the cylinder.

20. Measure the length, and the inside and outside diameters of a metal tube. If you have no inside calipers, bend a piece of annealed wire into a V-shape, and use that. (*a*) Compute the total surface area of the tube. (*b*) Compute the volume of metal in the tube. (*c*) Test your result by the displacement of water, as you did in Exercise 5 on page 13.

FIG. 8.

21. (*a*) With the inside calipers, measure the diameter of the tumbler on the inside, at the bottom and at the top. From these measurements determine the average diameter of the tumbler. Place

a straightedge (e.g., a ruler) across the top of the tumbler in the line of a diameter. Measure the perpendicular distance from the bottom of the tumbler to the under side of the straightedge. Compute the capacity of the tumbler in cubic centimeters. (*b*) Fill the tumbler with water and pour the water into the graduate, and thus test the accuracy of your previous measurements and computation.

III. THE THREE CONDITIONS OF MATTER, ETC.

23. Conditions of Matter. — *Matter exists in three conditions or forms, — the solid, the liquid, and the aëriform.* Gases and vapors are aëriform (i.e., having the form of air). Liquids and aëriform bodies are fluids.

24. A Solid *is a body whose molecules change their relative positions with difficulty.* Such bodies have a strong tendency to retain any form that may be given to them, and can sustain pressure without being supported at the sides.

25. A Fluid *is a body whose molecules easily change their relative positions.* Fluids cannot sustain pressure without being supported at the sides.

NOTE. — Review Experiment 8.

26. A Liquid *is a body whose molecules easily change their relative positions, yet tend to cling together.* Such bodies adapt themselves to the form of the vessel containing them, but do not retain that form when the restraining force is removed. Their free surfaces are always horizontal. Water is the best type of liquids.

27. An Aëriform Body *is one whose molecules easily change their relative positions, and tend to separate from each other almost indefinitely.* Gases remain aëriform under ordinary conditions, while vapors resume the solid

or liquid form at ordinary temperatures. Atmospheric air is the most familiar type of aëriform bodies.

28. Changes of Condition. — Many substances, like iron and gold and water, may be made to exist in all of these three forms by suitable adjustments of temperature and pressure. The identity of ice, water, and steam is familiar to all.

(*a*) Experiments with electric discharges in high vacuums have given results that many persons think prove the existence of a fourth condition of matter. For matter in this extremely thin or attenuated form, the name "radiant matter" has been proposed.

Solution.

Experiment 12. — Into a tumbler half full of water, drop a few lumps of sugar. Stir the contents of the glass until the solid disappears.

Experiment 13. — Mix 50 g. of pulverized ammonium nitrate and 25 g. of pulverized ammonium chloride (sal-ammoniac). Put the mixture into 75 cu. cm. of cold water in a tumbler, and stir the substances together with a small test-tube containing a little cold water. Notice that the solids disappear. Carefully observe the condition of the water in the test-tube.

29. Solution *is the transformation of matter from the solid or gaseous form to the liquid form by means of a liquid called the solvent or menstruum.* The process is essentially a change of molecular condition. When the change is from the solid to the liquid form, there is an absorption of heat and a fall of temperature, as is seen in freezing mixtures. The solution of a gas in a liquid is accompanied by a release of heat and a rise of temperature. When the solvent has dissolved as much of a given substance as it can, *the solution is said to be saturated.*

EXERCISES.

1. What is the difference between a fluid and a liquid?
2. Are molecules of water larger or smaller than those of steam? Give a reason for your answer.

3. Are intermolecular spaces greater in water or in steam? Give a reason for your answer.

4. Considered with reference to the three conditions of matter, are cohesion and heat coöperative, or antagonistic?

5. Ammonia gas is very largely soluble in water. Will such a solution of the ammonia warm or cool the water? Refer by number to the paragraph of this book that contains a statement that supports your answer.

6. Fill a clear glass tumbler with fresh hydrant or well water. Fill a similar vessel with water that has recently been well boiled. Set both in a moderately warm, quiet place, and let them stand over night. Examine the walls of the two tumblers, and account for the difference in their appearance.

Superficial Films.

Experiment 14. — Fill a tumbler brimming full of water. With a pipette (Fig. 9), or a pen-filler, add more water, drop by drop and patiently, until the water in the tumbler is actually heaped up higher than the edges of the glass. Try to imagine an invisible skin stretched over the liquid surface to keep it from overflowing the edge of the tumbler.

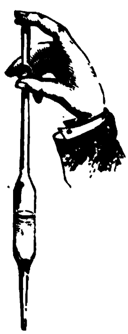

Fig. 9.

30. Superficial Films. — Every liquid may be regarded as bounded by a superficial film. This film is physically different from the interior of the liquid mass, and is a seat of energy. Two of the properties of these films are called surface viscosity and surface tension.

Surface Viscosity.

Experiment 15. — Carefully place a fine sewing needle upon the surface of water. With care, and perhaps repetition, the needle may be made to float. If you have serious trouble in making it float, draw it between the fingers or wipe it with an oily cloth. A hair-pin bent slightly near the tips may be used to lower the needle so that neither end shall touch the water before the other. Closely examine the surface of the water. Notice that the needle rests in a little depression or bed, just as it would if the surface of the water was a thin skin or membrane.

Fig. 10.

31. Surface Viscosity. — *The superficial film of a liquid is, as a rule, comparatively hard to move or break.*

(*a*) A solution of soap in water has greater surface viscosity than has pure water, hence its adaptability to the formation of bubbles. The surface viscosity of alcohol is very feeble. A rough sea is sometimes smoothed by pouring oil upon it. The new surface is comparatively rigid, and less easily broken into surf.

Surface Tension.

Experiment 16. — Float two sewing needles on the surface of water about a quarter of an inch apart, and let a drop of alcohol fall upon the water between them. Notice that the needles separate as if they had been supported on a stretched membrane, and the membrane had been cut so that its parts might separate, each carrying its needle with it.

Experiment 17. — Blow a soap-bubble without detaching it from the pipe or tube. Leave the tube open, and notice that the film contracts, diminishing the size of the bubble, and expelling some of the air from it. The current of air from the interior of the bubble may be made to deflect the flame of a candle.

32. Surface Tension. — Experiments show that *a liquid surface (as the surface that separates water from air, or oil from water) is in a state of tension* similar to that of a membrane stretched equally in all directions. Pure water has a surface tension higher than that of any other substance that is liquid at ordinary temperatures, except mercury; hence the mixture of any other liquid with water lessens the surface tension of the water, as in Experiment 16.

(*a*) The exterior and interior surfaces of a soap-bubble act like two sheets of india-rubber stretched equally in length and breadth. Their tendency to contract forces air from the interior of the bubble, as in Experiment 17.

(*b*) If a roughened wire ring is dipped into a strong solution of Castile soap, to which glycerin has been added, a plane film will be found stretched across it. To such a ring, tie a loop of thread and

secure another film, as shown in Fig. 11. With a hot wire, puncture the film inside the thread loop, and the tension of the film will pull the thread outward in all directions, as shown in Fig. 12.

FIG. 11.

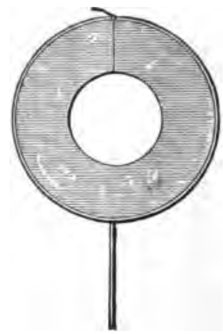

FIG. 12.

Capillary Attraction.

Experiment 18. — Partly fill a thin, clean beaker (or tumbler) with water, and a similar one with clean mercury. Notice that the upper surfaces of the two liquids are level *except at the edges near the glass.* Notice, further, that the water is lifted at the edge by the glass, and that the mercury is depressed.

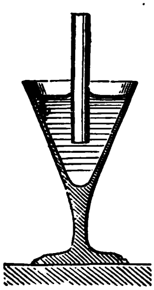

FIG. 13.

Experiment 19. — Support a clean glass rod vertically in the water, and notice that the liquid is lifted by the rod, as shown in Fig. 13. Remove the rod. *Notice that it is wet.* Wipe the rod dry, and place it similarly in the mercury. Notice that this liquid is depressed by the rod. Remove the rod, and *notice that it was not wetted by the mercury.*

Smear the glass rod with oil, and place it in the water, as before. Notice that the water is depressed thereby. Remove the rod, and notice that it is not wetted by the water.

33. Capillary Attraction. — The phenomena just noticed depend largely upon surface tension, and illustrate what is called *capillary attraction.* The truth suggested by our experiments is general: *All liquids that wet the sides of solids placed in them will be lifted, while those that do not will be pushed down.*

Capillary Tubes.

Experiment 20. — Wet the inner surfaces of several clean glass tubes of small and different diameters (1 mm. and less) to remove the ad-

hering air-film. Support the tubes vertically in pure water. Notice that the water rises in the tubes, as shown in Fig. 14; that, the less the diameter of the tube, the greater the elevation of the water; and that the free surface of the water in the tube is concave.

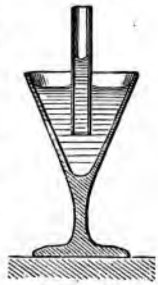

FIG. 14.

Remove the tubes, and similarly support them in clean mercury. Notice that the mercury is depressed in the tubes; that, the less the diameter of the tube, the greater the depression; and that the free surface of the mercury in the tubes is convex.

34. Capillary Tubes. — The effect of a capillary tube upon a liquid is due to the surface tension of the liquid. This tension produces an upward pull where the liquid surface is concave, and a downward pressure where the liquid surface is convex.

(*a*) Familiar illustrations of capillary action are numerous, such as the action of blotting-paper, sponges, lamp-wicks, etc.

Diffusion.

Experiment 21. — Wet the inner surface of a clear tumbler or beaker with strong ammonia water, leaving a few drops of the liquid in the bottom. Cover it with a sheet of writing paper. Moisten the inner surface of a like vessel with strong hydrochloric (muriatic) acid. Invert the second vessel over the first, mouth to mouth, so that the contents of the two vessels shall be separated only by the paper. Each vessel is filled with an invisible gas. Remove the paper, and notice that the invisible gases quickly diffuse into each other and form a dense cloud.

FIG. 15.

35. Diffusion. — *The gradual and spontaneous mixing of two fluids that are placed in contact is called diffusion.* It takes place even in opposition to the force of gravity. It is explained only by the motions and attractions of the molecules of the two fluids.

(*a*) Even with our most powerful microscopes, we cannot follow these motions or detect any currents. The motions are molecular, not molar.

36. Kinetic Theory of Gases. — A perfect gas consists of free, elastic molecules in constant and rapid motion. Each molecule moves in a straight line and with a uniform velocity until it strikes another molecule or the vessel in which the gas is contained. When these molecules encounter each other, they behave much as billiard balls would do if no energy was lost in their collisions. Each molecule travels a very small distance between one encounter and another, so that it is every now and then changing its velocity both in magnitude and direction. The magnitude of the velocity may be computed; one direction is just as likely as any other. Figure 16 represents the path that a molecule might travel in passing through a group of fixed molecules. It may help you to get a correct idea of the motion of a molecule, although, in fact, all of the molecules are in

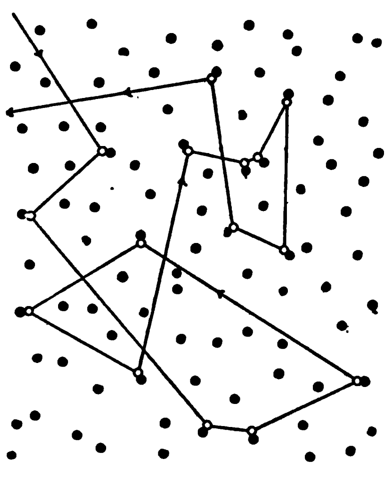

FIG. 16.

motion as well as the one that is represented by the open circle.

(*a*) It will be noticed that the diffusion of gases, as illustrated in Experiment 21, is a necessary consequence of these molecular motions. The blows upon the walls of the containing vessels are so numerous, that their total effect is a continuous, constant force or pressure. The path of a molecule between any two successive collisions is called its *free path*.

EXERCISES.

1. Why can you not blow a soap-bubble with pure water?

2. Why can you not float a 20-penny nail on water as you can a fine needle?

3. To what geometrical truth does the surface tension of a soap-bubble give an illustration?

4. In Experiment 19, we saw that mercury is depressed by a glass rod placed in it. How can you determine whether a clean strip of tin or zinc will lift or depress mercury?

5. What kind of motion is illustrated by the diffusion of two gases into each other?

6. State the kinetic theory of gases.

7. Is the free path of a molecule of steam greater or less than the free path of a molecule of liquid water? Why?

8. Carefully heat a tumbler, and half fill it with boiling water. Cover it with cardboard. Invert a second tumbler over the first. Watch the apparatus for a few minutes. If you notice any change in the appearance of the upper tumbler, find out whether it is due to a change in the inner or the outer surface of the glass. What property of the cardboard is thus illustrated?

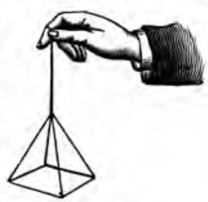

FIG. 17.

9. Make of No. 24 iron wire a skeleton of a square pyramid with edges 5 cm. long, and attach a handle, as shown in Fig. 17. Also make two wire rings 6 cm. in diameter and with wire handles. Make a soap-bubble solution as follows: Dissolve 5 g. of Castile soap, in fine shavings, in 200 cu. cm. of warm water, recently boiled, shaking the mixture from time to time. When the soap is dissolved, allow the solution to stand for several hours. Pour off the clear liquid, and to it add 125 cu. cm. of good glycerin, shaking the two thoroughly together.

(*a*) Slip a piece of rubber tubing over the shank of a glass funnel about 10 cm. across the top. Dip the edges of the funnel into the solution, catch a film, and blow as large a bubble as you can.

(*b*) Blow a bubble with a common clay pipe. Detach it from the pipe, and catch it on one of the iron rings. Bring the other ring into contact with the bubble on the other side, and draw the bubble into cylindrical form.

(*c*) Immerse the pyramidal frame into the solution, and try to secure a film on each side, thus forming a hollow, regular pentahedron.

CHAPTER II.

MECHANICS: MASS PHYSICS.

I. MOTION AND FORCE.

37. Mechanics *is the branch of physics that treats of forces and their effects.*

38. Motion, Velocity, and Acceleration.—*Motion is change of position. Velocity is rate of motion;* its magnitude is expressed by saying that it is such a distance in such a time, as ten miles an hour, or one meter a second. Velocity may be uniform or variable. A variable velocity is accelerated or retarded. *The change of velocity per unit of time (i.e., the rate of change of velocity) is called acceleration.* The acceleration is positive (+) if the velocity is accelerated, and negative (−) if the velocity is retarded.

(*a*) A body passing over unit of space in unit of time has unit velocity. The velocity per second multiplied by the number of seconds measures the distance traversed in any given time by a body moving with a uniform velocity. Representing these functions by l for distance, v for velocity per second, and t for time counted in seconds, we have

$$l = vt. \tag{1}$$

From this fundamental formula we derive algebraically the following:—

$$v = \frac{l}{t}, \text{ and } t = \frac{l}{v}.$$

If two of these values are known, they may be substituted in one of these formulas, and the third value obtained thence. If a body moves

at the rate of 50 feet per second for 12 seconds, and the distance traversed is desired, formula (1) is applicable: —

$$1 = vt = 50 \times 12 = 600, \text{ the number of feet.}$$

NOTE. — It is assumed that the pupil understands the easy manipulations of a simple algebraic equation. If he does not, the teacher should explain to him such as he finds in this book.

(*b*) Represent uniform increase of velocity (i.e., a constant acceleration) by a. In t seconds, a body starting from rest will have acquired a velocity represented by at.

$$v = at. \qquad (2)$$

This is the formula for a body starting from a state of rest, and having a uniformly accelerated velocity. Half the sum of the initial and the final velocities is the average velocity. In the case now under consideration, the initial velocity was zero, and the final velocity was at; therefore, the average velocity of a body starting from rest, and gaining a velocity uniformly accelerated for t seconds, is $\frac{0 + at}{2}$ or $\frac{1}{2}\,at$. The average velocity multiplied by the number of time-units equals the distance traversed; therefore, $l = \frac{1}{2}\,at \times t$, or

$$l = \tfrac{1}{2}\,at^2. \qquad (3)$$

Equating the values of t in equations (2) and (3), we may deduce the following: —

$$l = \frac{v^2}{2a}. \qquad (4)$$

(*c*) To find the distance passed over in any particular unit of time, it may be necessary to subtract the distance traversed in $t - 1$ units, from the distance traversed in t units, the whole time. Representing this distance traversed in a single time-unit by l', we have

$$l' = \tfrac{1}{2}\,at^2 - \tfrac{1}{2}\,a(t-1)^2;$$

therefore,

$$l' = \tfrac{1}{2}\,a(2t - 1). \qquad (5)$$

Example: Suppose that a body moving with a uniformly accelerated velocity starts from rest and passes over 7 meters in the first second. How far does it move in the next 3 seconds? If the body moves 7 meters in the first second under the conditions stated, its average velocity for that second is 7 meters, and its velocity at the end of that time is 14 meters. All of this velocity is gained in this single

second; hence, $a = 14$. Starting from rest, it moves 4 seconds; hence, $t = 4$. Substituting these values in formula (3),

$$l = \frac{1}{2} at^2 = \frac{1}{2} \times 14 \times 16 = 112,$$

the distance passed over in 4 seconds. From this, subtract the distance passed over in the first second, and we have 105, the number of meters passed over in the other 3 seconds, as called for. This solution illustrates the method of applying physical formulas to physical problems.

39. Momentum. — The result of the action of a force upon a body depends upon the mass of the body as well as upon its velocity. If m represents the mass of the body, and v its velocity, the product, mv, will represent its quantity of motion. *This product is called momentum.*

(*a*) The momentum of a body having a mass of 20 pounds and a velocity of 15 feet is twice as great as that of a body having a mass of 5 pounds and a velocity of 30 feet. The unit of momentum has no name.

40. Laws of Motion. — The following propositions are known as Newton's Laws of Motion: —

(1) *Every body continues in its state of rest or of uniform motion in a straight line unless compelled to change that state by an external force.*

(2) *Every change of motion (momentum) is in the direction of the force impressed, and is proportionate to it.*

(3) *Action and reaction are equal and opposite in direction.*

EXERCISES.

1. Find the momentum of a 500-pound ball moving 500 feet a second.

2. By falling a certain time, a 200-pound ball has acquired a velocity of 321.6 feet. What is its momentum?

3. A boat that is moving at the rate of 5 miles an hour weighs 4 tons; another that is moving at the rate of 10 miles an hour weighs 2 tons. How do their momenta compare?

4. What kind of motion is caused by a single, constant force? Illustrate your answer.

5. A stone weighing 12 ounces is thrown with a velocity of 1,320 feet per minute. An ounce ball is shot with a velocity of 15 miles per minute. Find the ratio between their momenta.

6. An iceberg of 50,000 tons moves with a velocity of 2 miles an hour. An avalanche of 10,000 tons of snow descends with a velocity of 10 miles an hour. Which has the greater momentum?

7. Two bodies weighing respectively 25 and 40 pounds have equal momenta. The first has a velocity of 60 feet a second. What is the velocity of the other?

8. Two balls have equal momenta. The first weighs 100 Kg., and moves with a velocity of 20 m. a second. The other moves with a velocity of 500 m. a second. What is its weight?

9. A railway train moves at the rate of 40 miles an hour. Express its velocity per second in feet.

10. If the mean distance of the earth from the sun is 92,390,000 miles, and it requires 16 minutes 36 seconds for a ray of light to pass over the diameter of the earth's orbit, what is the velocity of light expressed in miles per second?

41. Units of Force. — *The gravity unit of force is the weight of any standard unit of mass, as the kilogram or pound. The absolute unit of force is the force that, acting for unit of time upon unit of mass, will produce unit of acceleration (i.e., change of velocity).*

(*a*) The foot-pound-second (F.P.S.) unit of force is the force that, applied to one pound of matter for one second, will produce an acceleration of one foot per second. It is called a *poundal.* The centimeter-gram-second (C.G.S.) unit of force is the force that, acting for one second upon a mass of one gram, produces an acceleration of one centimeter per second. It is called a *dyne.* The poundal and the dyne are absolute units and are invariable in value.

(*b*) A force is measured in poundals or dynes by multiplying the number of units of mass moved by the number representing the acceleration produced, only such units being used as are indicated by the initials F.P.S. or C.G.S. respectively. The acceleration may be determined by dividing the total velocity that the force has produced by the number of seconds that the force has acted.

(*c*) The simplest way of measuring a force is to use a dynamometer, of which the spring-balance (Fig. 18) is a familiar example. The dynamometer may be graduated in pounds, grams, poundals, or dynes.

FIG. 18.

EXERCISES.

1. A railway train 120 yards long moves at the rate of 30 miles an hour. How long will it take to pass completely over a bridge 120 feet long?

2. At the sea-level at New York a force of 25 pounds equals how many poundals? (See § 68.) *Ans.* 804.

3. Under the same conditions, a force of 5 Kg. equals how many dynes? (See § 68.) *Ans.* 4,900,000.

4. A poundal equals how many dynes?

5. Compare the momentum of a 64-pound cannon ball moving with a velocity of 1,300 feet per second, with that of an ounce bullet moving with a velocity of 400 yards per second.

6. What property of matter is illustrated in the removal of dust from a carpet by beating?

42. Graphic Representation of Forces. — *Forces may be represented by lines*, the point of application determining one end of the line, the direction of the force determining the direction of the line, and the magnitude of the force determining the length of the line.

(*a*) It will be noticed that these three elements of a force are the ones that define a line. By drawing the line as above indicated, the units of force being numerically equal to the units of length, we have a complete graphic representation of the given force. The unit of length adopted in any such representation may be determined by convenience; but, the scale once determined, it must be adhered to throughout the problem. Thus, the diagram represents two forces applied at the point *B*. These forces act at right angles to each other. The arrowheads indicate that the forces represented act from *B* toward *A* and *C* respectively. The

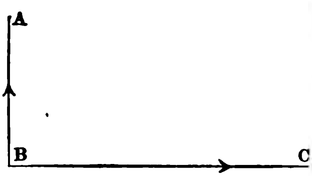

FIG. 19.

force that acts in the direction, BA, being 20 lbs., and the force acting in the direction, BC, being 40 lbs., the line, BA, must be one-half as long as BC. The scale adopted being 1 mm. to the pound, the smaller force will be represented by a line 2 cm. long and the greater force by a line 4 cm. long.

43. Resultant. — Motion may be produced by the joint action of two or more forces. The single force that will produce an effect like that of the component forces acting together is called the *resultant*. The single force that, acting with the component forces, will keep the body at rest is called the *equilibrant*. The resultant and the equilibrant of any set of component forces are equal in magnitude, and opposite in direction.

The point of application, direction, and magnitude of each of the component forces being given, the direction and magnitude of the resultant are found by a method known as the "composition of forces."

Composition of Forces.

Experiment 22. — Suspend two similar spring-balances from any convenient support, as shown in Fig. 20. From the wooden rod carried by their hooks, suspend a known weight. Be sure that the dynamometers hang vertical, and therefore parallel. Record the readings of A and B. Carefully measure the distances CD and DE, and record them. If the dynamometers are accurate, the work has been carefully done, and the weight of the rod is inconsiderable, the results should show that

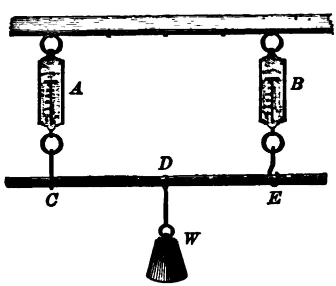

Fig. 20.

$$W = A + B, \text{ and that } \frac{A}{B} = \frac{DE}{CD}.$$

If the weight of the rod is considerable, place the rod in the hooks, and notice the readings of the dynamometers. Then hang the weight from the rod, and let A and

B represent the *increase* in the readings of the dynamometers. The result should be as given above.

44. Composition of Forces. — Forces may be compounded in several ways, the more important of which are the following: —

(1) *When the component forces act in the same direction and along the same line. The magnitude of the resultant is then the sum of the given forces.* Example: Rowing a boat down-stream.

(2) *When the component forces act in opposite directions and along the same line. The magnitude of the resultant is then the difference between the given forces.* Motion will be produced in the direction of the greater force. Example: Rowing a boat up-stream.

(3) *The resultant of two forces that act in the same direction along parallel lines has a magnitude equal to the sum of the magnitudes of the components, and its point of application divides the line joining the points of application of the components inversely as the magnitudes of said components.* This principle is illustrated by Experiment 22.

(4) *When two equal parallel forces act at different points on a body and in opposite directions, the arrangement constitutes what is called a couple. It produces rotary motion, and the components can have no resultant.*

(5) *When the component forces have a given point of application (i.e., when they are "concurring forces") and act at an angle with each other, as when a boat is rowed across a stream, the resultant may be ascertained by the "parallelogram of forces."*

Parallelogram of Forces.

Experiment 23. — Support two spring-balances, *B* and *C*, from *P* and *S*, two nails in the frame of the blackboard. Hook them, with a third dynamometer, *D*, into a small ring, *Z*, as shown in Fig. 21.

Pull steadily on I in some downward direction. Mark on the board the centers of the rings, Z and I, and record the readings of the three dynamometers. Remove the apparatus, and through the points indicated draw on the board the lines ZP, ZS, and ZI. Using any convenient scale, lay off the lines ZE, ZA, and ZI, proportional to the readings of the respective dynamometers. Complete the parallelo-

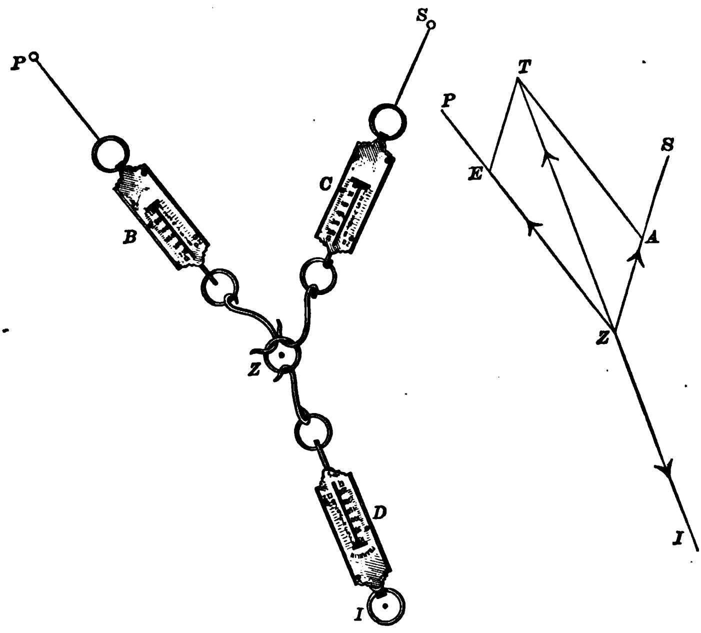

Fig. 21.

gram, $ZETA$. Draw the diagonal, ZT, measure its length, and determine the magnitude that it represents according to the scale adopted. If the work has been accurately done, ZI and ZT will be equal in value, and form a straight line. ZT is the resultant, and ZI is the equilibrant, of the components, ZE and ZA. Place the apparatus horizontal and repeat the work.

45. Parallelogram of Forces. — In the diagram, let AB and AC represent two forces acting upon the point, A.

Draw the two dotted lines to complete the parallelogram. From A, the point of application, draw the diagonal, AD. *This diagonal will be a complete graphic representation of the resultant.* If two forces, such as those represented in the diagram, act simultaneously upon a body at A, that body will move over the path represented by AD, and come to rest at D.

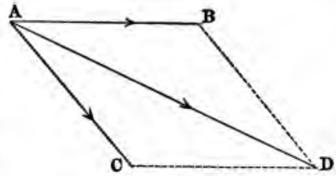

FIG. 22.

(*a*) If more than two forces concur, the resultant of any two may be combined with a third, their resultant with a fourth, and so on. The last diagonal will represent the resultant of the given forces. As is indicated by Fig. 23, it is not necessary that all of the forces act in the same plane.

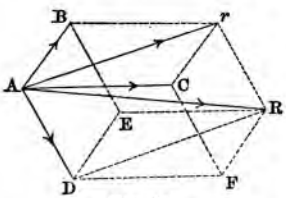

FIG. 23.

(*b*) The converse of the composition of forces, i.e., the *process of finding the components to which the given force is equivalent is called the resolution of forces.* Represent the given force by a line; on this line as a diagonal, construct a parallelogram. The two sides of the parallelogram that meet at either end of the diagonal will represent the component forces. An infinite number of such parallelograms may be constructed on a single diagonal unless some condition is added to make the problem definite.


FIG. 24.

Reaction.

Experiment 24. — Make a railway of two wooden strips $1\frac{1}{2}$ inches by $\frac{1}{4}$ inch, and about 6 feet long, fastened together by three or five crosspieces, as shown in Fig. 24. The distance between the rails

should be about an inch. Place the railway on a board, and fasten down the middle crosspiece with a screw. Spring up the ends, and support them by books or wooden blocks. At the toy shop, get several large glass marbles, or other elastic balls, and place them on the middle of the railway. Bring one ball to the highest point of the track, and let it roll down against the others. Ball No. 1 gives its motion to No. 2, and comes to rest; No. 2 gives it to No. 3, and in turn comes to rest. The energy is thus passed through the line to No. 7, which is driven some distance on the up grade, as to the position shown by the dotted line at 8. Repeat the experiment after replacing the middle ball by a lead ball of the same size.

Experiment 25. — From any convenient support, as the door frame, hang two bags of shot or of sand by strings of equal length and so that they will just touch each other. They should be of equal weight. If one is drawn aside and let fall against the other, both will move forward, but only half as far as the first would had it met no resistance. The gain of momentum by the second is due to the action of the first. It is equal to the loss of momentum by the first, which loss is due to the reaction of the second. If the experiment is repeated with elastic balls (glass or ivory), it will be found that the first ball will give the whole of its motion to the second, *and remain still after striking*. The balls may be suspended by gluing a narrow strip of leather to each, leaving a little loop at the middle of the strip for the fastening of the string.

46. Elasticity and Reaction. — The effects of action and reaction are modified largely by elasticity, but never so as to destroy their equality.

47. Reflected Motion *is the motion produced in a body by the reaction between it and another body against which it strikes.* A ball rebounding from the wall of a house or from the cushion of a billiard table is an example of reflected motion.

(*a*) The angle, *ABD*, included between the direction of the moving body before it strikes the reflecting surface, and a perpendicular to that surface drawn from the point of contact, is called the *angle of incidence.* The angle between the perpendicular and the direction of the moving body after striking is called the *angle of reflection.*

48. Law of Reflected Motion. — *When the bodies are perfectly elastic, the angle of incidence is equal to the angle of reflection, and lies in the same plane. When the elasticity of the bodies is imperfect, the angle of reflection is greater than the angle of incidence.*

(*a*) If a glass or ivory ball is shot from *A* (Fig. 25) against an elastic surface at *B*, the center of the semicircle, it will be reflected back to *C*, making the angles, *ABD* and *CBD*, equal. If the ball or the body at *B* is not perfectly elastic (e.g., if a lead ball is used), the angle of reflection will be greater than the angle of incidence.

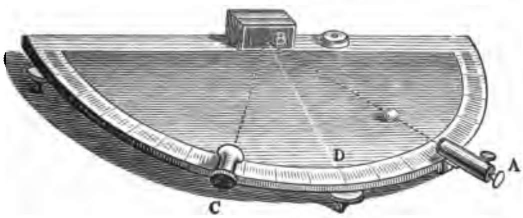

FIG. 25.

49. Curvilinear Motion. — When a ball at the end of a string is whirled around the hand, there is a pull on the string. The ball is pulled from the straight path which it tends to follow in accordance with the first law of motion, and is thus compelled to move in a curved line. There are evidently two forces involved in the production of such a motion. The resistance offered by the body to its deflection from a rectilinear path is due to its inertia, and is commonly called by the ill-chosen name, "centrifugal force." From this point of view, *centrifugal force may be defined as the reaction of a moving body against the force that makes it move in a curved path.*

(*a*) Examples and effects of this so-called centrifugal force may be suggested as follows: the water flying from a revolving grindstone, erosion of river-beds, a pail of water whirled in a vertical circle, the

inward leaning of the circus horse and rider, elongation of the equatorial diameter of the earth, etc.

EXERCISES.

1. Represent graphically the resultant of two forces, 100 and 150 pounds respectively, exerted by two men pulling a weight in the same direction. Determine its value.

2. In similar manner, represent the resultant of the same forces when the men pull in opposite directions. Determine its value.

3. Suppose an attempt is made to row a boat at the rate of 4 miles an hour directly across a stream flowing at the rate of 3 miles an hour. Determine the direction and velocity of the boat.

4. A flag is drawn steadily downward 64 feet from the masthead of a moving ship. During the same time, the ship moves forward 24 feet. Represent the direction and length of the actual path of the flag.

5. A sailor climbs a mast at the rate of 3 feet a second. The ship is sailing at the rate of 12 feet a second. Over what space does he actually move during 20 seconds?

6. A force of 1,000 dynes acts on a certain mass for one second, and gives it a velocity of 20 cm. per second. What is the mass in grams? *Ans.* 50.

7. A constant force, acting on a mass of 12 g. for one second, gives it a velocity of 6 cm. per second. Find the force in dynes.

8. A force of 490 dynes acts on a mass of 70 g. for one second. What velocity will be produced? *Ans.* 7 cm. per second.

9. Draw two lines bisecting each other at right angles, and mark the ends of the lines to represent the cardinal points of the compass, as in a map. From the intersection of the two lines draw another line to represent the velocity of a United States cruiser steaming south of southeast at the rate of 19 miles an hour. Determine the rate of the southerly and the easterly motions of the ship. Record on your diagram the scale used.

II. WORK AND ENERGY.

50. Work.—In physical science, the word "work" *signifies the overcoming of resistance of any kind.* Work implies a change of position, and is independent of the time taken to do it. When a force moves a body, it is said to do work

on that body. When the expansive force of steam presses against the piston of an engine and overcomes the resistance, i.e., *when it moves the piston*, it does work.

(*a*) A man who is supporting (not lifting) a heavy weight may be putting forth great effort, but he is not doing work.

51. Units of Work. — Four work-units are in use; viz., the foot-pound and the kilogrammeter (gravitation units), and the foot-poundal and the erg (absolute units).

(1) *The foot-pound is the amount of work required to raise one pound one foot high against the force of gravity.*

(2) *The kilogrammeter is the amount of work required to raise one kilogram one meter high against the force of gravity.*

(3) *The foot-poundal is the amount of work done by a force of one poundal in producing a displacement of one foot.* The number of foot-pounds multiplied by the number of feet in the acceleration due to gravity (§ 68) equals the number of foot-poundals; thus, at New York, a foot-pound is equivalent to 32.16 foot-poundals.

(4) *The erg is the amount of work done by a force of one dyne producing a displacement of one centimeter.* Since there are 980,000 dynes in the weight of one kilogram of matter at New York, a kilogrammeter there equals 98,000,000 ergs. A foot-poundal is equivalent to 421,402 ergs; a foot-pound is equivalent to 32.16 times that many ergs.

(*a*) To get a numerical estimate of work done, we multiply the number of units of force by the number of units of displacement: —

$$\textit{Work done} = fl.$$

Since the resistance overcome is numerically equal to the force acting, the work done may be computed by multiplying, in a similar manner, the resistance by the space: —

$$\textit{Work done} = wl.$$

In this formula, w represents the resistance; and l, the length or distance. When the body is simply lifted against the force of gravity,

w represents weight. A weight of 25 pounds raised 3 feet, or one of 3 pounds raised 25 feet, represents 75 foot-pounds. A weight of 15 kilograms raised 10 meters represents 150 kilogrammeters.

52. Activity and Horse-Power.—In measuring work done, no consideration is given to the time taken. In considering an engine or other agent that is to do the work, the time required is a very important thing. *The activity of an agent is the rate at which it can do work, and is measured by the work it can do in unit time. The unit in most common use for the measurement of activity is the horse-power. It represents the ability to do* 550 *foot-pounds per second.*

$$H.P. = \frac{pounds \times feet}{550 \times seconds}.$$

(*a*) The practical unit of electrical activity is the watt. One horse-power equals 746 watts.

53. Energy *is the power of doing work. Energy of motion is called kinetic energy; energy of position is called potential energy.*

(*a*) A falling weight or running stream possesses energy of motion. Before the weight began to fall, it had the power of doing work by reason of its elevated position with reference to the earth. When the water of the running stream was at rest in the lake among the hills, it had a power of doing work, an energy that was not possessed by the waters of the pond in the valley below.

(*b*) Kinetic and potential energies are convertible each into the other. Imagine a ball thrown upward with a velocity that will keep it in motion for two seconds. At the end of one second it has lost some of its velocity, and hence some of its kinetic energy; but it has gained an elevated position, and has, therefore, acquired some potential energy. At the end of another second it has no velocity, and, therefore, no kinetic energy. But the energy with which the ball began its upward flight has not been annihilated; it has been wholly converted into potential energy. If we ignore the disappearance (not loss) of the energy expended in overcoming the resistance of the air,

the ball would, when permitted to fall, reach the level from which it started with undiminished velocity and kinetic energy.

(*c*) The pendulum affords a good illustration of kinetic and potential energy, their equivalence and convertibility. When the pendulum hangs at rest in a vertical position, as *Pa*, it has no energy at all. If we draw the pendulum aside to *b*, we raise it through the space, *ah*; that is, we do work upon it, and endow it with potential energy. As it swings through its arc, the two types of energy vary from all potential at *b* or *c*, to all kinetic at *a*. At every instant, and at every point of the arc, the sum of the kinetic and potential energies ($K.E. + P.E.$) is an unvarying quantity, always equal to the energy originally spent in swinging it from *a* to *b*.

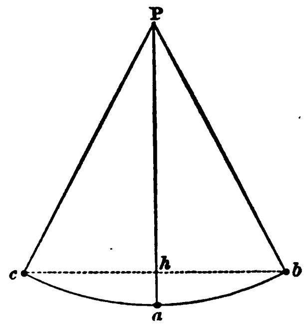

FIG. 26.

Velocity and Energy.

Experiment 26. — Into a pail full of moist clay or stiff mortar, drop a bullet from the height of one yard. Notice the depth to which the bullet penetrates. Drop the bullet from a height of four yards. It will strike the clay with twice the velocity, and penetrate four times as far as it did before. This suggests that perhaps an increase in the velocity of a given body increases the energy of that body more rapidly than it increases the momentum.

54. Kinetic Energy Measured. — The energy of a moving body may be measured by the units used in measuring work; i.e., in units of force and displacement. Neither the direction of the motion, nor the manner of expenditure, changes the amount of energy expanded. We may, therefore, find to what vertical height the given velocity would lift the body (§ 70), and thus determine its energy in foot-pounds or kilogrammeters.

(*a*) Representing the weight of a body by *w*, and the vertical height to which its velocity can carry it by *l*, it is evident that the

kinetic energy can do $w \times l$ units of work. From the formulas for falling bodies (§ 69), we may derive the following:—

$$l = \frac{v^2}{2g},$$

in which g represents the acceleration due to gravity, i.e., 32.16 feet or 980 cm. Substituting this value of l in the equation given above, we have

$$\textit{Kinetic Energy} = \frac{wv^2}{2g}.$$

If w is measured in pounds and v in feet, this measures the energy in foot-pounds; if w is measured in kilograms and v in meters, it measures the energy in kilogrammeters.

(*b*) From Newton's second law of motion (§ 40) it follows that a force may be measured by the momentum it produces. Representing force by f, mass by m, and acceleration by a, we have

$$f = ma.$$

But the measurement of work (§ 51, *a*) introduces the additional factor, l, representing the number of units of displacement. Introducing this factor into the equation above, we have, for work or kinetic energy,

$$K.E. = fl = mal.$$

In § 38 (*b*) we have

$$l = \frac{v^2}{2a}.$$

Substituting this value of l in the second member of the equation above, we have

$$K.E. = fl = \frac{mav^2}{2a} = \tfrac{1}{2} mv^2.$$

If m is measured in pounds and v in feet, this formula gives a numerical expression for foot-poundals; if m is measured in grams and v in centimeters, it gives that expression for ergs.

55. Potential Energy Measured. — In the case of a body raised above the surface of the earth, its potential energy may be measured,

(1) In gravitation units, by the product $w \times h$.

(2) In absolute units, by the product $m \times h \times g$.

56. Conservation of Energy. — Except for friction and the resistance of the air, a swinging pendulum would oscillate forever. Energy is withdrawn from the pendulum to overcome these impediments, but the energy thus withdrawn is not destroyed. What becomes of it will be seen when we study heat. The truth is that *energy is as indestructible as matter; this is what is meant by the "conservation of energy."*

EXERCISES.

1. What is the horse-power of an engine that will raise 8,250 pounds 176 feet in 4 minutes?

2. A ball weighing 192.96 pounds is rolled with a velocity of 100 feet a second. How much energy has it? *Ans.* 30,000 foot-pounds.

3. A projectile weighing 50 Kg. is thrown obliquely upward with a velocity of 19.6 m. How much kinetic energy has it?

4. What is the horse-power of an engine that can raise 1,500 pounds 2,376 feet in 3 minutes? *Ans.* 36 H.P.

5. A cubic foot of water weighs about $62\frac{1}{2}$ pounds. What is the horse-power of an engine that can raise 300 cubic feet of water every minute from a mine 132 feet deep?

6. A body weighing 100 pounds moves with a velocity of 20 miles per hour. Find its kinetic energy.

7. How long will it take a 2-horse-power engine to raise 5 tons 100 feet?

8. How far can a 2-horse-power engine raise 5 tons in 30 seconds?

9. What is the horse-power of an engine that can do 1,650,000 foot-pounds of work in a minute?

10. What is the horse-power of an engine that can raise 2,376 pounds 1,000 feet in 2 minutes?

11. A railway car weighs 10 tons. From a state of rest it is moved 50 feet, when it is moving at the rate of 3 miles an hour. If the resistances from friction, etc., are 8 pounds per ton, how many foot-pounds of work have been expended upon the car? (First find the work done in overcoming friction, etc., through 50 feet, which is 50 foot-pounds × 10 × 8. To this, add the work done in giving the car kinetic energy.)

12. Determine, by the composition of forces, whether three con-

curring forces with magnitudes of 5, 6, and 12 pounds, respectively, can be in equilibrium.

13. Explain why a soap-bubble blown at one end of a tube contracts, and forces a current of air out of the other end of the tube.

III. GRAVITATION, ETC.

57. Gravitation. — *Every particle of matter in the universe has an attraction for every other particle. This attractive force is called gravitation.*

58. Law of Gravitation. — *The mutual attraction between two bodies varies directly as the product of their masses, and inversely as the square of the distance between their centers of mass.* For example, doubling this product doubles the attraction; doubling the distance quarters the attraction; doubling both the product and the distance halves the attraction.

59. Gravity. — The attraction between the earth and bodies upon or near its surface is a form of gravitation that is commonly called *gravity.* Its measure is *weight.* Its direction is that of the plumb line, vertical.

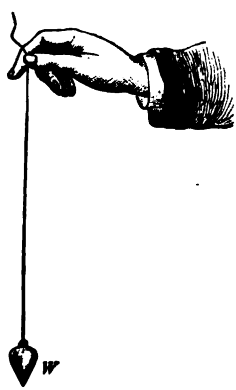

FIG. 27.

60. The Weight of a terrestrial object is the measure of the attraction between it and the earth. The weight of a body at one place on the surface of the earth may differ from its weight at another place, because the earth is not a perfect sphere and its density is not uniform.

61. Law of Weight. — *Bodies weigh most at the surface of the earth. For bodies in the earth's crust, the weight varies approximately as the distance from the center. For bodies above the earth's surface, the weight varies inversely as the square of the distance from the center.*

62. Center of Mass. — A body's center of mass is a point the distance of which from any plane is equal to the average distance of the whole mass from the same plane. The same point may be the center of gravity.

(*a*) The center of gravity may be considered the point of application of the resultant of many equal and parallel forces, one of which acts upon each particle of the body.

(*b*) In a freely falling body, no matter how irregular its form or how nearly indescribable the curves made by any of its projecting parts, the *line of direction* in which the center of mass moves is a vertical line.

(*c*) In some bodies, as a ring or box or hollow sphere or cask, the center of mass does not lie in the matter of which the body is composed.

63. The Base. — *The side on which a body rests is called its base.* If the body is supported on legs, as a chair, the base is the polygon formed by joining the points of support.

64. Equilibrium. — A body supported at a single point will rest in equilibrium when a vertical line passing through its center of mass, i.e., the line of direction, also passes through the point of support. A body supported on a surface will rest in equilibrium when the line of direction (§ 62, *b*) falls within its base. The center of mass will be supported when it coincides with the point of support, or is in the same vertical line with it. When the center of mass is supported, the whole body is supported and rests in a state of equilibrium.

(*a*) When a body is supported in such a way that a slight displacement raises its center of mass, it is said to be in *stable equilibrium.*

When such a displacement lowers the center of mass, the body is said to be in *unstable equilibrium.* When such a displacement neither raises nor lowers the center of mass, the body is said to be in *neutral* or *indifferent equilibrium.*

(*b*) The stability of a body is measured by the amount of work that must be done to overturn it. This amount may be increased by enlarging the base, or by lowering the center of mass, or both.

(*c*) When the body rests upon a point, as does the sphere, or upon a line, as does the cylinder, a very slight force is sufficient to move it, no elevation of the center of mass being necessary.

EXERCISES.

1. Suppose the earth to be solid. How far below the surface would a 10-pound ball weigh only 4 pounds?

Solution. — As the weight is to be reduced six tenths, it must be carried 0.6 of the way to the center.

Ans. 4,000 miles × 0.6 = 2,400 miles.

2. On the same supposition, what would a body weighing 550 pounds on the surface of the earth weigh 3,000 miles below the surface? *Ans.* $137\frac{1}{2}$ pounds.

3. Two bodies attract each other with a certain force when they are 75 m. apart. How many times will the attraction be increased when they are 50 m. apart? *Ans.* $2\frac{1}{4}$.

4. Why does a person stand less firmly when his feet are parallel and close together than when they are more gracefully placed?

FIG. 28.

5. Why can a child walk more easily with a cane than without?

6. Why will a book placed on a desk-lid stay there, while a marble will roll off?

7. Why is a ton of stone on a wagon less likely to upset than a ton of hay similarly placed?

8. Why have the Egyptian pyramids great stability?

9. A boy placed a step-ladder as shown in Fig. 28, and it stood. Why? He then climbed to its top, and it fell. Why?

10. Drive small tacks into the frame of a slate at adjacent corners. Tie the middle of a stout thread to one of the tacks. Fasten a small weight to one end of the thread, and support the apparatus from the

other end. Mark on the slate the direction in which the thread crosses it. Similarly support the slate by the other tack, and mark the direction of the thread by another line. Place the intersection of the two lines over the end of the finger, and see if the slate is balanced. The point thus located approximately represents what?

11. Cut a rectangle from cardboard. Draw its two diagonals. Balance the cardboard to see how near the center of mass coincides with the center of area. Can the center of mass lie on the surface of such a body?

12. Drive a wire nail into a vertical support, and cut off the head of the nail. Bore several holes through an irregularly shaped board near its edges. Using one of these holes, hang the board on the nail. From the nail, hang a chalked plumb line. When the plumb line has come to rest, "snap" it so as to make a vertical line on the board. Change the position of the board, the nail passing through another of the holes. Chalk the line, suspend and "snap" as before. Place the intersection of the two chalk lines over the end of the finger, and see if the board then balances. Using another hole, similarly chalk another line, and see if the three lines have a common point of intersection.

13. Cut a piece of board 20″ long, 3″ wide at one end, and 7″ wide at the other end. Find a point on the surface of the board as near as possible to the center of mass, and over it paste a patch of black paper one inch in diameter. On the same side of the board, and a foot or so from the other paper, paste a patch of red paper about 2″ in diameter. Toss the board up edgewise in the open air, so that it will turn end over end, carefully observing the motion of the two paper patches relative to each other. Record and explain what you see.

IV. FALLING BODIES.

65. Freely Falling Bodies. — When a body is left unsupported and free to move under the influence of the force of gravity and without any resistance, it is a freely falling body.

(*a*) If we ignore the resistance of the air, the laws for falling bodies may, without sensible error, be considered the same as for uniformly accelerated motion.

Comparison of Velocities.

Experiment 27. — From the upper window, drop simultaneously an iron and a wooden ball of the same size. Be careful that your fingers do not "stick" to one ball longer than to the other. Notice that the two balls of different weight strike the ground at practically the same time.

66. Velocities of Falling Bodies. — When a feather and a cent are dropped from the same height, the cent reaches the ground first. This is because the feather meets with more resistance from the air in proportion to its mass. The resistance may be avoided by dropping them in a glass tube from which the air has been removed. The resistances may be nearly equalized by making the two falling bodies of the same size and shape but of different weights, as in the preceding experiment.

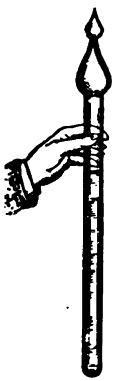

FIG. 29.

(*a*) When water falls over a high precipice, the resistance of the air breaks part of it into spray before it reaches the bottom. In a vacuum, water falls as a solid, as may be shown with a *water-hammer*, an instrument made by partly filling a stout glass tube with water, boiling the water that the steam may expel the air, and sealing the tube.

Impeded Fall.

Experiment 28. — Tack a strip of wood half an inch square to the straight edge of a plank 16 feet long. Fasten metal strips an inch wide to the sides of the wooden strip so as to make a double-track way which should be straight and smooth. Divide the edge of the plank on one side of the track into 16 foot-spaces, plainly marked. Raise one end of the plank a foot higher than the other. Place a glass or an iron ball at the top of the inclined track. Notice how often the class-room clock ticks in a second. Place a finger on top of the ball, thus holding it ready for a start. Repeat the word "tick" in unison with the clock until you "feel" the rhythm of its swing, and, just at the moment of a "tick," lift the finger from the ball, which will begin to roll down the track. Notice and record the position of the ball at

the end of successive seconds. To locate the ball at the end of the allotted period, place on the upper side of the half-inch strip a wooden block just wide enough to hold its position, and just thick enough to produce an easily audible click when struck by the ball. By trial, place this block so that the tick and the click shall coincide. Repeat your observations, and average the results of similar trials. The greater the number of carefully conducted trials, the more valuable will be your averages.

The ball will roll down the inclined plane, about 1 foot in the first second, 4 feet in 2 seconds, 9 feet in 3 seconds, 16 feet in 4 seconds, etc. The average results may be tabulated as follows:—

Number of Seconds.	*Spaces fallen each Second.*	*Velocities at the End of each Second.*	*Total Number of Spaces fallen.*
1	1	2	1
2	3	4	4
3	5	6	9
4	7	8	16
t	$2t-1$	$2t$	t^2

Representing the velocity gained each second (acceleration) by a, and, consequently, the value of each of our spaces by $\frac{1}{2}a$, we have, from the above, the already familiar formulas, $l' = \frac{1}{2}a(2t-1)$; $v = at$; and $l = \frac{1}{2}at^2$ (see § 38).

67. Unimpeded Fall. — By giving a greater inclination to the plane used in Experiment 28, the ball will roll more rapidly; when the plane becomes vertical, we may say that the ball becomes a freely falling body. Our unit of space has now become 16.08 feet, or 490 centimeters. The ball will fall this distance during the first second, three times this distance during the next second, five times this distance during third second, and so on.

68. Acceleration Due to Gravity. — In the latitude of New York, a freely falling body gains a velocity of 32.16 feet, or 980 centimeters, during the first second of its fall. It makes a like gain of velocity during each subsequent second of its fall. *This distance is, therefore, called the*

acceleration due to gravity, and is generally represented by the letter g.

69. Formulas for Falling Bodies. — The formulas for freely falling bodies may be derived from those for uniformly accelerated motion (§ 38) by substituting the definite quantity, g, for the indefinite quantity, a. Hence, we have for bodies starting from rest: —

$$(1)\ v = gt.$$
$$(2)\ l' = \tfrac{1}{2} g\,(2t - 1).$$
$$(3)\ l = \tfrac{1}{2} gt^2.$$

(*a*) For bodies rolling down an inclined plane, these formulas may be made applicable by multiplying the value of g by the ratio between the height and the length of the plane.

(*b*) None of these formulas involve any expression for mass, thus indicating that the velocity of a falling body is not affected by its mass.

70. Laws of Falling Bodies. — For bodies starting from rest, these formulas may be translated as follows: —

(1) *The velocity of a freely falling body at the end of any second of its descent is equal to* 32.16 *feet* (980 *cm.*) *multiplied by the number of the second.*

(2) *The distance traversed by a freely falling body during any second of its descent is equal to* 16.08 *feet* (490 *cm.*) *multiplied by one less than twice the number of the second.*

(3) *The distance traversed by a freely falling body during any number of seconds is equal to* 16.08 *feet* (490 *cm.*) *multiplied by the square of the number of seconds.*

(*a*) A body may be thrown downward as well as dropped. In such a case the effect of the throw must be added to the effect of gravity.

$$v = gt + V;\ l' = \tfrac{1}{2} g\,(2t - 1) + V;\ l = \tfrac{1}{2} gt^2 + Vt.$$

When a body is thrown vertically upward, the time of the ascent may be found by dividing the initial velocity by the acceleration of gravity.

Projectiles.

Experiment 29. — From a strip of wood shaped like a meter stick or common lath, cut a piece about 10 cm. long. Cut equal notches at two corners, *a* and *e*, as shown in Fig. 30. Nail the middle of this piece across the end of the rest of the lath, thus making a T-shaped form. Clamp the other end of the long leg firmly in a vise so that the edge *ae*, and the corresponding edge of the long piece, shall be horizontal and several feet above a level floor. Place lead bullets at *a* and *e*. Strike the long piece a sharp, horizontal blow near the crosspiece. One of the bullets will be shot horizontally, and the other will be dropped nearly vertically. Will the bullets strike the floor at the same time? Repeat the experiment several times, and do not expect more than approximate agreements.

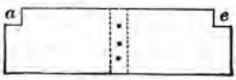

FIG. 30.

71. Projectiles. — Every projectile is acted upon by an impulsive force and the force of gravity. The path of a projectile is a parabolic curve, the resultant of these forces.

EXERCISES.

1. What will be the velocity of a body after it has fallen 4 seconds?

Solution: — $v = gt = 32.16 \times 4 = 128.64$. *Ans.* 128.64 feet.

2. A body falls for several seconds. During one of these seconds it passes over 530.64 feet. Which one is it?

Solution: — $l' = \frac{1}{2} g(2t - 1)$

$530.64 = 16.08 \times (2t - 1)$; $\therefore t = 17$.

Ans. 17th second.

3. A body was projected vertically upward with a velocity of 96.48 feet. How high did it rise?

$$\textit{Solution:} — t = \frac{v}{g} = \frac{96.48}{32.16} = 3.$$

$$l = \tfrac{1}{2} gt^2 = 16.08 \times 9 = 144.72. \quad \textit{Ans. } 144.72 \text{ feet.}$$

4. How far will a body fall during the third second of its fall?
5. How far will a body fall in 10 seconds? *Ans.* 1608 feet.
6. How far in $\frac{1}{2}$ second? *Ans.* 4.02 feet.
7. How far will a body fall during the first second and a half of its fall?

8. A stone is thrown horizontally from the top of a tower 257.28 feet high, with a velocity of 60 feet a second. Where will it strike the ground? *Ans.* 240 feet from the tower.

9. A body was five seconds rolling down an inclined plane, and passed over 7 feet during the first second. Give (*a*) the entire space passed over, and (*b*) the final velocity.

10. A body falls freely for 6 seconds. What is the space traversed during the last two seconds of its fall?

11. From the frame of a small pulley running with little friction suspend a weight of about 2 pounds. Place the wheel of the pulley so that it will run on a No. 10 wire tightly stretched between opposite sides of the room, one end of the wire being a little higher than the other. The wire may be tightened with a turnbuckle. Just above the wire, and parallel with it, stretch a cord. From the upper end of the wire start the pulley with its load, and note the point where it is at the end of 3 seconds. If the distance traversed in the 3 seconds is not at least 9 feet, increase the inclination of the wire. Mark the point where the pulley is at the end of the third second by a strip of paper hung from the cord so that its lower end will be struck by the top of the pulley as it passes. Mark the point on the cord above the starting point of the pulley by tying a thread there. Divide the intervening distance into 9 equal parts. Hang similar paper strips from the cord, at distances of 5 such equal parts and of 8 such equal parts above the strip already hung, and of 7 such equal parts and 16 such equal parts below it.

Swing the pendulum that vibrates seconds. As its thread passes a vertical line on the wooden support drawn downward from the needle, start the pulley, and see if it taps the successive strips as the pendulum successively passes the vertical line. If the weight carried by the pulley is of iron, the weight and the pendulum-bob may be simultaneously released as in Exercise 1.

NOTE.— A good Atwood machine is an expensive piece of apparatus, and unfortunately many schools and laboratories have none. If any particular school is thus equipped, the teacher should provide for its use in the verification of the laws of falling bodies, the approximate determination of the acceleration due to gravity, etc.

12. From a rectangular wooden block about 30 × 23 × 4 cm., cut a semi-cycloid, thus shaping the piece marked *B* in Fig. 31. Cut a groove in the curved edge, and fasten the block against the blackboard so that its long edge shall be vertical. A small ball that has

rolled down the cycloidal path will be projected with a constant horizontal velocity and will acquire an accelerated vertical velocity. Let one of two pupils working together adjust, by repeated trials, a ruler so that the projected ball will just touch it, and thence determine and mark the point passed over by *the center* of the ball. In this way locate points sufficiently numerous to plot on the blackboard the path described by the center of the projected ball. From the center of the ball at the lowest point of its cycloidal path draw a horizontal line, and mark off a number of equal spaces upon it. These will represent the horizontal motions of the ball in equal intervals of time. From each division on this line, draw a vertical line, l, to the plotted path, and measure the lengths of these lines. They represent the spaces fallen in the several intervals of time. Show that, for each interval of time, $l = kt^2$, k being some constant. If the horizontal intervals are made equal to the horizontal speed of the ball per second, k will equal $\frac{1}{2}g$.

FIG. 31.

V. THE PENDULUM.

72. A Simple Pendulum *is a single material particle supported by a line without weight, and capable of oscillating about a fixed point.* Such a pendulum has a theoretical but not an actual existence. Its properties may be approximately determined by experimenting with a small lead ball suspended by a fine thread.

(*a*) Cut a bullet halfway through. Tie a knot in the end of the thread, place the knot in the cut in the bullet, and, with a blow, close the lead upon it.

(*b*) When the pendulum is drawn from its vertical position, as from N to M, the force of gravity, MG, is resolved into two compo-

nents, one of which, *MC*, produces pressure at the point of support, while the other, *MH*, acts at right angles to it, producing motion toward *N*. As the pendulum approaches *N*, its kinetic energy increases. This energy carries the weight beyond *N* toward *O*, with transformation of energy and continued motion as explained in § 53 (*c*).

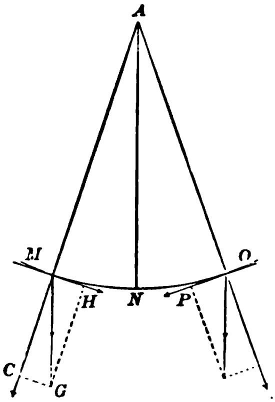

FIG 32.

73. Definitions. — The motion from one extremity of the arc through which a pendulum swings to the other is called an *oscillation.* The time occupied in moving over this arc is called the *time* or *period of oscillation.* The angle measured by half this arc is called the *amplitude of oscillation.* The trip from *M* to *O* is an oscillation. The angle, *MAN*, is the amplitude of oscillation.

(*a*) The motion from *M* to *O* and back again, one "swing-swang," is sometimes called a "complete vibration." The time occupied by the round trip, or the time between its passage through any point and its next passage in the same direction through the same point, is sometimes called a "complete period."

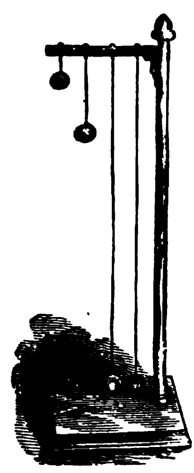

FIG. 33.

Laws of the Pendulum.

Experiment 30. — Suspend three lead bullets and a small iron ball as shown in the accompanying figure. The lengths of the threads, measured between the points of support and the centers of the balls, should be as $1 : \frac{1}{4} : \frac{1}{9}$; e.g., 1 yard, 9 inches, and 4 inches respectively. Set one of the pendulums swinging through a small arc, and count the oscillations made in 10 seconds. Set the same pendulum swing-

ing through a somewhat larger arc, and count the oscillations as before. Record and compare results. Repeat the experiments with each of the pendulums, recording and comparing results in each case. Note the effect of amplitude or of mass on the period of oscillation.

From your notes, or by fresh experiment, determine the period of each pendulum, and observe the relation between the period of oscillation and the length of the pendulum.

Place a magnet under the iron ball, so that when the latter swings it will just clear the end of the magnet. Swing the iron pendulum, and count the oscillations made in 10 seconds. The attraction of the magnet being added to that of the earth, the acceleration is increased and the period is lessened.

74. Laws of the Pendulum. — When the amplitude of oscillation is small, the period of oscillation depends mainly upon the length of the pendulum and the acceleration due to gravity.

The following laws are consistent with the results of numberless experiments: —

(1) *At any given place, the oscillations of a given pendulum are isochronous*, i.e., are made in equal periods.

(2) *The period of oscillation is independent of the material or the mass of the pendulum.*

(3) *The period of oscillation varies directly as the square root of the length.*

(4) *The period of oscillation varies inversely as the square root of the acceleration.*

75. The Compound Pendulum. — *Any pendulum other than the simple or ideal pendulum is a compound pendulum.* In its most common form, it consists of a slender rod, flexible at the top, and carrying at the bottom a heavy mass of metal known as the *bob.*

76. The Seconds Pendulum. — *At any given place, a seconds pendulum is one that makes a single oscillation in a second.* At the sea-level, its length is about 39 inches

at the equator, and about 39.2 inches near the poles. Its value at the sea-level at New York may be found by making $t = 1$, and $g = 980.19$ cm., in the formula

$$t = \pi\sqrt{\frac{l}{g}},$$

and solving the equation for the value of l.

(*a*) The Greek letter π represents the ratio between the diameter and the circumference of a circle. See Appendix 1.

Center of Oscillation.

Experiment 31. — Drive a small wire nail through a flat board of any form, at some point near its edge, as shown in Fig. 34. Hold the ends of the wire by the finger and thumb, and allow the board to hang in a vertical plane. Fasten a small bullet to the end of a thread, and pass the thread over the wire so that the bullet hangs close to the board. Move the hand that supports the wire horizontally and in the plane of the board. Board and bullet will swing as pendulums. If one swings more rapidly than the other, lengthen or shorten the string until they swing together. With the thread at this length, and board and bullet hanging in equilibrium, mark the point on the board opposite the center of the ball. Holding the board by the wire as before, move it with varied, sudden, and irregular motions in the plane of the board. The bullet will not quit the marked place on the board.

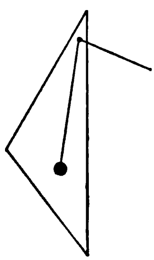

FIG. 34.

77. Centers of Suspension and Oscillation. — In every pendulum not simple, the parts near the center of suspension tend to move faster than those further away, and force the latter to move more rapidly than they otherwise would. Between these, there is a particle that moves, of its own accord, at the rate forced upon the others. This particle fulfills all the conditions of a simple pendulum that has the period of the compound pendulum. Its position is called the *center of oscillation or percussion.*

(*a*) Fig. 35 represents a wooden bar, suspended so as to have freedom of motion about the point *S*, which thus becomes the center of suspension. *G* indicates the center of mass, and *O* the center of oscillation. *S* and *O* are interchangeable; i.e., if the pendulum is suspended from its center of oscillation, the period remains the same.

(*b*) If we consider the length of the compound pendulum to be the distance between the centers of suspension and oscillation, all the laws of the simple pendulum become applicable to the compound pendulum.

FIG. 35.

EXERCISES.

NOTE.—Take 39.1 inches or 99.33 centimeters as the length of a seconds pendulum.

No.	Inches.	Oscillations.	Period.	No.	Cm.	Oscillations.	Period.
1	?	20 per min.	?	11	99.33	?	?
2	?	30 "	?	12	?	?	2 sec.
3	30	?	?	13	?	?	2 min.
4	16	?	?	14	24.83	?	?
5	?	?	$\frac{1}{4}$ sec.	15	?	8 per sec.	?
6	?	?	$\frac{1}{4}$ min.	16	397.32	?	?
7	39.37	? per min.	?	17	11.03	?	?
8	?	10 "	?	18	?	?	10 sec.
9	10	? per sec.	?	19	2,483 25	?	?
10	?	1 per min.	?	20	?	?	4 sec.

21. How will the periods of oscillation of two pendulums compare, their lengths being 4 feet and 49 feet respectively? *Ans.* As 2 : 7.

22. Of two pendulums, one makes 70 oscillations a minute, the other, 80 oscillations a minute. How do their lengths compare? *Ans.* As 64 : 49.

23. If one pendulum is 4 times as long as another, what are their relative periods of oscillation?

24. The length of a seconds pendulum being 39.1 inches, what must be the length of a pendulum to oscillate in $\frac{1}{5}$ second?

25. How long must a pendulum be to oscillate (*a*) once in 8 seconds? (*b*) In $\frac{1}{8}$ second?

26. **Set up a pendulum of length as great as you can conveniently. Set up another that oscillates just twice as often in a given time. Determine the ratio between the lengths of the two pendulums. Shorten the shorter pendulum until it oscillates three times as fast as the other. Determine the relative lengths as before. Shorten the shorter pendulum again until it oscillates four times as fast, and find the ratio as before. In your notebook, record the data obtained, using the following form, and placing the ascertained ratios in the places of** x, y, **and** z**: —**

Relative Numbers of Oscillations.	*Relative Lengths.*
1	1
2	x
3	y
4	z
5	?
6	?

FIG. 36.

Can you see any law or rule governing in such cases? Try, without experiment, to put the proper figures in the places of the two interrogation points.

27. On a stout thread, fasten 5 or 6 lead bullets at successive intervals of 10 cm., and suspend the combination as a pendulum. Swing it as a pendulum. Does the string retain its rectilinear form while the compound pendulum is oscillating? Account for any observed difference in this respect between this pendulum and those previously used.

28. Through the laboratory meter stick or a similar strip of wood, drill or burn a small hole 3 cm. from one end. Using this as a center of suspension, locate the center of oscillation. Determine the real length of the meter-stick pendulum. Suspend a bullet by a single thread, and adjust its length so that it will swing with the same period as the meter-stick pendulum. Compare the length of this pendulum with the distance between the centers of suspension and oscillation of the other pendulum.

29. Remove the dial of a clock, and study the movements of the escapement (*mn* in Fig. 36), and of the

escapement wheel, *R*. What does it enable the lifted weights or the coiled spring of the clock to do to the pendulum? What does it enable the pendulum to do to the weights or the spring? What would happen to the weights or to the spring if the escapement should be suddenly removed? What would happen to the pendulum if the escapement should be removed? How many times must the pendulum oscillate that the escapement wheel may turn around once?

VI. SIMPLE MACHINES.

78. Machines. — *In mechanics, the word "machine" signifies an instrument for the conversion of motion or the transference of energy.* Thus, a machine may be designed to convert rapid motion into slow motion; e.g., a crowbar.

FIG. 37.

(*a*) No machine can create or increase energy. In fact the use of a machine is accompanied by a waste of the energy that is needed to overcome the resistances of friction, the air, etc.

79. Weight and Power. — The action of a machine involves two forces, called the *weight* and the *power*. *The power signifies the magnitude of the force that acts upon one part of the machine; the weight signifies the magnitude of the force exerted by another part of the machine upon some external resistance.* The general problem relating to machines is to find the ratio between power and weight; i.e., to determine the "mechanical advantage" of the machine.

80. General Laws of Machines. — In every machine, the work done by the power equals the work done on the weight.

(1) *The power multiplied by the distance through which it moves equals the weight multiplied by the distance through which it moves:* $Pl = Wl'$.

(2) *The power multiplied by its velocity equals the weight multiplied by its velocity:* $Pv = Wv'$.

81. Efficiency of Machines. — *The ratio that the useful work done by the machine bears to the total work done on the machine is called the efficiency of the machine.* If this ratio could be brought up to unity, we should have a perfect machine, — the impossible thing that would supply "perpetual motion."

(*a*) Whenever we find that a machine does less work than was done upon it, we should bear in mind that the missing energy has not been destroyed. Mechanical energy has been transformed into molecular energy, and exists somewhere in the form of heat.

82. Friction *is the resistance that a moving body meets from the surface on which it moves,* and may be rolling or sliding. It is due partly to the adhesion of bodies, but more largely to their roughness. Even highly polished surfaces have minute irregularities, and when two such surfaces come into contact, the projections of one fall into the depressions of the other. When one slides over the other, energy is required to break off the projections or to lift the body out of the depressions.

(*a*) Friction is generally lessened by polishing and lubricating the surfaces that move upon each other, and often by making the two bodies of different material.

83. A Lever *is an inflexible bar freely movable about a fixed axis called the fulcrum.* Every lever is said to have two arms. The power arm is the perpendicular distance from the fulcrum to the line in which the power acts; the weight arm is the perpendicular distance from the fulcrum to the line in which the weight acts. If the

arms are not in the same straight line, the lever is called a bent lever.

(*a*) There are three classes of levers, depending upon the relative positions of power, weight, and fulcrum. If the fulcrum is between the power and weight (*PFW*), the lever is of the first class (Fig. 38); if the weight is between the other two (*PWF*), the lever is of the second class; if the power is between the other two (*WPF*), the lever is of the third class.

FIG. 38.

84. Mechanical Advantage of the Lever. — *With a lever, a given power will support a weight as many times as great as itself as the power arm is times as long as the weight arm.*

(*a*) If the power arm is twice as long as the weight arm, the power will move twice as fast and twice as far as the weight does, i.e., the ratio between the arms is the same as the ratio between the velocities or distances traversed. The power multiplied by the power arm equals the weight multiplied by the weight arm.

NOTE. — In all experimental work, the lever should be loaded so as to be in equilibrium before the power and weight are applied. It is to be noticed that, when we speak of the power multiplied by the power arm, we refer to the abstract numbers representing the power and power arm. We cannot multiply pounds by feet, but we can multiply the number of pounds by the number of feet.

85. The Moment of a Force *with respect to a given point is its tendency to produce rotation about that point, and is measured by the product of the numbers representing respectively the magnitude of the force and the perpendicular distance between the given point and the line of the force.*

(*a*) In the case of the lever represented in Fig. 38, the weight arm is 8 mm., and the power arm is 30 mm. Suppose that the power is 4 grams and represent the weight by x. Then the moment of the force acting on the power arm will be represented by $(4 \times 30 =)$ 120, and the moment of the force acting on the weight arm by $8\,x$.

86. The Balance *is essentially a lever of the first class, having equal arms.* The beam carries a pan at each end, — one for the weights used, the other for the article to be weighed.

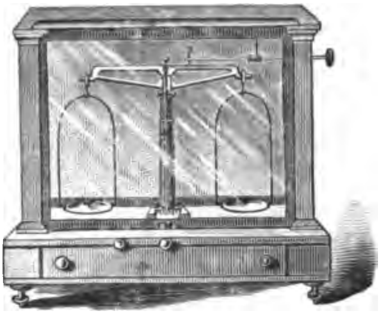

FIG. 39.

(*a*) Dishonest dealers sometimes use balances with arms of unequal lengths. The true weight may be found by weighing the article first on one side and then on the other, and finding *the square root of the product of the two false weights.* Another way is to place the article to be weighed in one pan, and counterpoise it, as with shot or sand placed in the other pan. Remove the article, and place known weights in the pan until they balance the shot or sand in the other pan. These known weights will represent the true weight of the article in question.

EXERCISES.

1. If a power of 50 pounds acting upon any kind of machine moves 15 feet, (*a*) how far can it move a weight of 250 pounds? (*b*) How great a load can it move 75 feet?

2. If a power of 100 pounds acting upon a machine moves with a velocity of 10 feet per second, (*a*) to how great a load can it give a velocity of 125 feet per second? (*b*) With what velocity can it move a load of 200 pounds?

3. A lever is 10 feet long with its fulcrum in the middle. A power of 50 pounds is applied at one end. (*a*) How great a load at the other end can it support? (*b*) How great a load can it lift?

Ans. (*b*) Anything less than 50 pounds.

4. The power arm of a lever is 10 feet. The weight arm is 5 feet. (*a*) How long will the lever be if it is of the first class? (*b*) If it is of the second class? (*c*) If it is of the third class?

5. A bar 12 feet long is to be used as a lever, keeping the weight 3 feet from the fulcrum. (*a*) What class or classes of levers may it represent? (*b*) What weight can a power of 10 pounds support in each case?

6. The length of a lever is 10 feet. Four feet from the fulcrum and at the end of that arm is a weight of 40 pounds; two feet from the fulcrum, on the same side, is a weight of 1,000 pounds. What force at the other end will counterbalance both weights?

Ans. 360 pounds.

7. The length of a lever is 8 feet, and its fulcrum is in the center. A force of 10 pounds acts at one end; 1 foot from it is another of 100 pounds; 3 feet from the other end is a force of 100 pounds. The direction of all the forces is downward. Where must a downward force of 80 pounds be applied to balance the lever?

Ans. 3 feet from the fulcrum.

8. The length of a lever is 3 feet. Where must the fulcrum be placed so that a weight of 200 pounds at one end shall be balanced by 40 pounds at the other end?

9. In one pan of a false balance, a roll of butter weighs 1 pound 9 ounces; in the other, 2 pounds 4 ounces. Find the true weight.

10. A and B, at opposite ends of a bar 6 feet long, carry a weight of 300 pounds suspended between them. A's strength being twice as great as B's, where should the weight be hung?

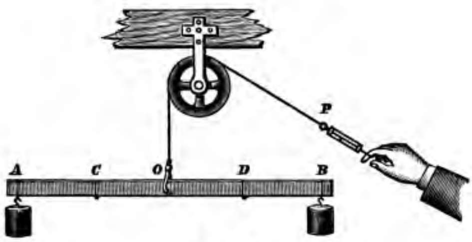

FIG. 40.

11. Support a wooden bar, preferably graduated (the yardstick or the meter rod will answer admirably), by a pin and clevis at the middle of its length, as shown in Fig. 40. Put the bar in equilibrium (as in all such experimental cases), and provide stops 2 or 3 inches below each end of the bar to limit its oscillations. Support equal and known weights by thread loops at equal distances from the middle of the lever, and compare the reading of the dynamometer with the sum of the suspended weights. Do they agree? If not, why not? Make the necessary correction.

12. Modify the apparatus used in Exercise 11 by removing the dynamometer and adding a counterpoise, as shown in Fig. 41. Replace the weight at *A* with one twice as heavy, and shift its position until the bar is in equilibrium. Note the distances of *C* and *B* from *O*. Using either form of apparatus, load the two arms of the lever with weights of varying ratios, and note the agreement or disagreement of your results with the several statements made in §§ 80 and 84.

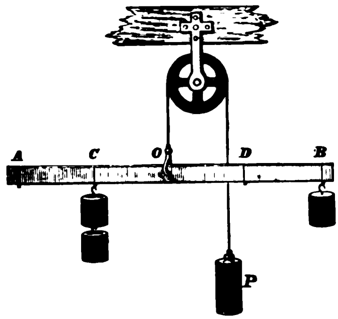

FIG. 41.

13. Take two points at *slightly* different distances from *O*, the fulcrum of the balance-beam. Suspend an unknown weight from one of these points, and counterpoise it with known weights at the other point so taken. Verify the statements made in § 86 (*a*).

14. From one of the points taken as directed in Exercise 12, suspend a tin can, and put the lever in equilibrium. From the other of those two points, suspend a body of unknown weight, and find its true weight by the process of double weighing, as described in § 86 (*a*).

87. The Wheel and Axle *consists of a wheel united to a cylinder in such a way that they may turn together on a common axis.*

FIG. 42.

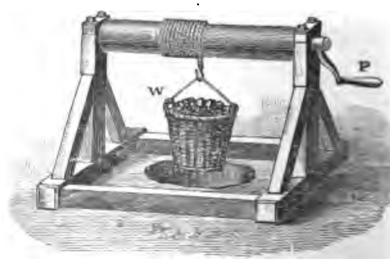

FIG. 43.

(*a*) It is not necessary that an entire wheel be present, a single spoke or radius being sufficient for the application of the power, as in the case of the windlass (Fig. 43) or the capstan (Fig. 44).

(*b*) The advantage of the wheel and axle may be increased by combining several, so that the axle of the first may act on the wheel of the second, and so on, as shown in Fig. 45.

FIG. 44.

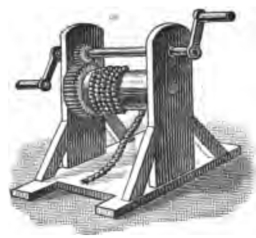

FIG. 45.

88. Mechanical Advantage of the Wheel and Axle. — *The mechanical advantage of this machine equals the ratio between the radii, diameters, or circumferences of the wheel and of the axle.*

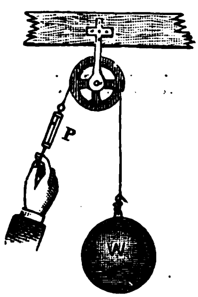

FIG. 46.

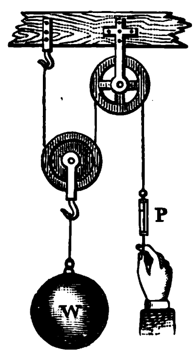

FIG. 47.

89. A Pulley *is a wheel having a grooved rim for carrying a rope or other line, and turning on an axis carried in a frame, called a pulley block.* The pulley is fixed if the block is stationary (Fig. 46); the pulley is movable if the block moves during the action of the power (Fig. 47).

FIG. 48.

(*a*) Combinations of pulleys are made in great variety. In the forms most commonly used, one continuous cord passes around all the pulleys. Frequently two or more sheaves are mounted in the same block and turn on the same axis, as in the common block and tackle, shown in Fig. 48.

90. Mechanical Advantage of the Pulley. — With the ordinary arrangement of pulleys, like the block and tackle, *a given power will support a weight as many times as great as itself as there are parts of the cord supporting the movable block.*

$$W = P \times n.$$

(*a*) In experiments to determine the mechanical advantage of a system of pulleys, as in all similar experiments, see that the apparatus is in equilibrium before applying P and W.

91. An Inclined Plane *is a smooth, hard, inflexible surface, inclined so as to make an oblique angle with the horizon.*

FIG. 49.

(*a*) When a body is placed on an inclined plane, the gravity pull is resolved into two component forces. One of these acts perpendicularly to the plane, producing pressure on it, the other component tending to produce motion down the plane. To resist this last-mentioned tendency, and thus to hold the body in its position, a force may be applied in three ways: —

(1) In a direction parallel to the length of the plane.
(2) In a direction parallel to the base of the plane; i.e., horizontal.
(3) In a direction parallel to neither the length nor the base.

92. Mechanical Advantage of the Inclined Plane. — (1) *When a given power acts parallel to an inclined plane, it will support a weight as many times as great as itself as the length of the plane is times as great as its vertical height.*

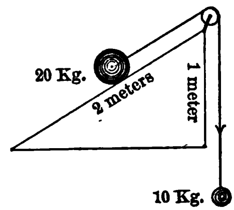

FIG. 50.

(2) *When a given power acts horizontally, it will support a weight as many times as great as itself as the horizontal base of the plane is times as great as its vertical height.*

(*a*) When the power acts in a direction parallel to neither the length nor the base, no law can be given.

EXERCISES.

1. The pilot wheel of a boat is 3 feet in diameter; the axle, 6 inches. The resistance of the rudder is 180 pounds. What power applied to the wheel will move the rudder?

2. Four men are hoisting an anchor of 1 ton weight. The barrel of the capstan is 8 inches in diameter. The circle described by the handspikes is 6 feet 8 inches in diameter. How great a pressure must each of the men exert?

3. A capstan whose barrel has a diameter of 14 inches is worked by two handspikes, each 7 feet long. At the end of each handspike a man pushes with a force of 30 pounds; 2 feet from the end of each handspike a man pushes with a force of 40 pounds. Required the effect produced by the four men.

4. With a fixed pulley, what power will support a weight of 50 pounds?

5. With a movable pulley, what power will support a weight of 50 pounds?

6. With block and tackle, the fixed block having four sheaves and the movable block having three, what weight may be supported by a power of 75 pounds? If an allowance of $\frac{1}{5}$ is made for friction and rigidity of ropes, what is the maximum weight that may be thus supported?

7. With a system of five movable pulleys, one end of the rope being attached to the fixed block, what power will raise a ton?

8. If, in the system mentioned in Exercise 7, the rope is attached to the movable block, what power will raise a ton? If an allowance of 25 per cent is made for friction and rigidity of ropes, what power will be required?

9. How great a power will be required to support a ball weighing 40 pounds on an inclined plane whose length is 8 times its height?

10. The base of an inclined plane is 10 feet; the height is 3 feet. What force, acting parallel to the base, will balance a weight of 2 tons?

93. A Wedge is a triangular prism of hard material, fitted to be driven between objects that are to be separated, or into anything that is to be split. *It is simply a movable inclined plane, or two such planes united at their bases.* The power is generally applied in repeated blows on the thick end or "head." For a wedge thus used, no law of any practical value can be given, further than that, with a given thickness, the longer the wedge, the greater the mechanical advantage.

FIG. 51.

94. A Screw *is a cylinder, generally of wood or metal, with a spiral ridge (the thread) winding about its circum-*

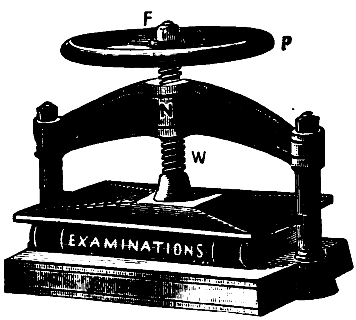

FIG. 52.

FIG. 53.

ference. The thread works in a nut, within which there is a corresponding spiral groove to receive the thread.

(*a*) The power is generally applied by a wheel or a lever, and moves through the circumference of a circle. The distance between two consecutive turns of any continuous thread, measured in the direction of the axis of the screw, is called the *pitch of the screw*.

95. Mechanical Advantage of the Screw. — *With the screw, a given power will support a weight as many times as great as itself as the circumference described by the power is times as great as the pitch of the screw.*

96. Compound Machines. — When any two or more of these simple machines are combined, the mechanical advantage may be found by computing the effect of each separately, and then compounding them; or by finding the weight that the given power will support, using the first machine alone, considering the result as a new power acting upon the second machine, and so on.

EXERCISES.

1. A bookbinder has a press, the screw of which has a pitch of $\frac{1}{4}$ of an inch. The nut is worked by a lever that describes a circumference of 8 feet. How great a pressure will a power of 15 pounds applied at the end of the lever produce, the loss by friction being equivalent to 240 pounds?

2. A screw has eleven threads for every inch in length. If the lever is 8 inches long, the power 50 pounds, and friction absorbs $\frac{1}{8}$ of the energy used, what resistance may be overcome by it?

3. A screw with threads $1\frac{1}{4}$ inches apart is driven by a lever $4\frac{1}{2}$ feet long. What is the mechanical advantage of the apparatus?

4. At the top of an inclined plane that rises 1 foot in 20 is a wheel and axle. The radius of the wheel is $2\frac{1}{2}$ feet; radius of axle, $4\frac{1}{2}$ inches. What load may be lifted by a boy who turns the wheel with a force of 25 pounds?

5. In moving a building, the horse is harnessed to the end of a lever 7 feet long, acting on a capstan barrel 11 inches in diameter. On the barrel winds a rope belonging to a system of 2 fixed and 3 movable pulleys. What force will be exerted by 500 pounds power, allowing $\frac{1}{4}$ for loss by friction?

6. Experimentally determine the ratio of power to weight with

pulleys arranged as shown in Fig. 54. The pulleys and the cord should be strong enough to carry a load of 100 pounds.

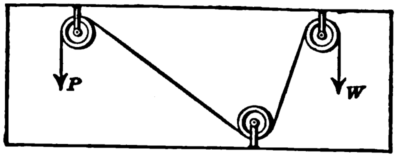

FIG. 54.

7. Determine the loss due to friction and to the rigidity of the ropes used in Exercise 6.

8. Experimentally determine the ratio between P and W with pulleys arranged as shown in Fig. 55. Determine the law of such a combination.

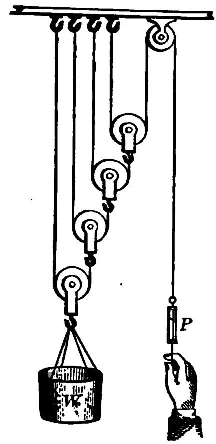

FIG. 55.

VII. THE MECHANICS OF LIQUIDS.

97. Compressibility and Elasticity of Liquids. — Liquids are nearly incompressible. When the pressure is removed, the liquids regain their former volume, showing thus their perfect elasticity. The practical incompressibility of liquids is of great mechanical importance.

Liquid Pressure.

Experiment 32. — Tie a piece of thin sheet rubber (such as you can get from the druggist or dentist, or from a broken toy balloon) over the large end of a lamp-chimney. Reinforce the other end by winding upon it a dozen turns of wrapping twine, and fit it with a fine-grained cork or rubber stopper through which passes snugly a bit of glass tubing. Connect the glass tubing and a supported funnel by two or three feet of rubber tubing. Fill the apparatus with water, loosening the cork

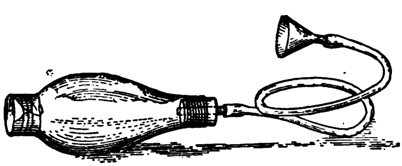

FIG 56.

for a moment to allow the escape of air. See that the funnel is still half full of water and elevated above the chimney. Notice the effect of the water pressure on the sheet rubber. Hold the chimney in various positions, keeping the center of the sheet rubber at a uniform distance below the level of the funnel, and notice whether the elastic sheet is stretched more or less when the liquid pressure upon it is horizontal, upward, or downward. Then try it at varying distances below the level of the water in the funnel, and determine whether such vertical distance or "head" has any relation to the pressure.

98. Transmission of Pressure. — *Fluids transmit pressures in every direction.*

(*a*) Figure 57 represents a number of balls placed in a vessel. Imagine these balls to have perfect freedom of motion and perfect elasticity. It is evident that if a downward pressure, say of 10 grams, is applied to 2, it will force 5 and 4 toward the left, and 6, 7, and 8 toward the right, thus forming lateral pressure. This motion of 5 will force 1 upward, and 9 downward, etc. Owing to the perfect elasticity and freedom of motion, there will be no loss, and the several balls will be moved just as if the original pressure had been applied directly to each one. The pressure will be thus transmitted to all of the balls without loss, and the total pressure exerted on the sides of the vessel will equal 10 grams multiplied by the number of balls that touch the sides. It makes no difference with the result whether the pressure exerted by 2 was the result of its own weight only, this weight together with the weight of overlying balls, or both of these with still additional pressure.

FIG. 57.

(*b*) Disregarding viscosity, we may consider a fluid to be made up of molecules having the perfect elasticity and freedom of motion assumed for the balls just discussed. Hence, when pressure is applied to one or more of the molecules of a fluid, the pressure will be transmitted as now explained.

99. Pascal's Law. — *Pressure exerted anywhere upon a liquid inclosed in a vessel is transmitted undiminished in all directions, and acts with the same force upon all equal surfaces, and in a direction at right angles to those surfaces.*

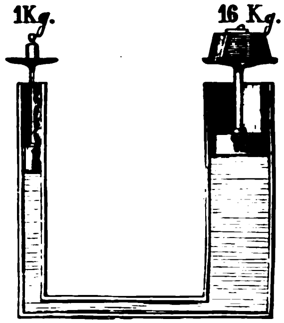

FIG. 58.

(*a*) Provide two communicating tubes of unequal sectional area. When water is poured into these, it will stand at the same height in both tubes, — a fact which of itself partly confirms the law above given. If the smaller piston has an area of 1 sq. cm., and the larger piston an area of 16 sq. cm., a weight of 1 Kg. may be made to support a weight of 16 Kg.

100. The Hydraulic Press. — Pascal's law finds an important application in the hydraulic press, in the more common forms of which the pressure of a piston operated by a lever

FIG. 59.

is transmitted through a pipe to a piston of larger area. The press is represented in Fig. 59.

(*a*) If the power arm of the lever is ten times as long as the weight arm, a power of 50 Kg. will exert a pressure of 500 Kg. upon the water beneath the piston, *a*. If this piston has a sectional area of 1 sq. cm., and the piston, *C*, has an area of 500 sq. cm., then the pressure of 500 Kg. exerted by the small piston will produce a pressure of 500 Kg. × 500 or 250,000 Kg. upon the lower surface of the large piston.

Downward Pressure.

Experiment 33.—Into a U-tube, pour enough mercury to fill each arm to the depth of 3 or 4 cm. Place the U-tube upon a table, and hold it upright by any convenient means. Back of it, and resting against it, stand a card having a horizontal line, *a*, drawn on it to mark the level of the mercury in the two arms of the tube. To one arm, attach the neck of a funnel by means of a bit of rubber tubing. The funnel may be held by the ring of a retort stand. Pour water slowly into the funnel until it is nearly full, and mark the level of the water by a suspended weight or other means. In one arm, the mercury will be depressed below the line marked on the card; in the other arm, it will be raised above it an equal distance. Mark these two mercury levels by dotted horizontal lines on the card. Remove the funnel and replace it by a funnel- or thistle-tube, making the connection by means of a perforated cork. Pour water into the funnel-tube until it stands at the level indicated by the suspended weight, *being careful that no air is confined in the tubes*. Although much less water is in the funnel-tube than was in the funnel, it forces the mercury into the position indicated by the dotted lines on the card. The downward pressure of the water in each case is measured by a mercury column with a height, *ce*,

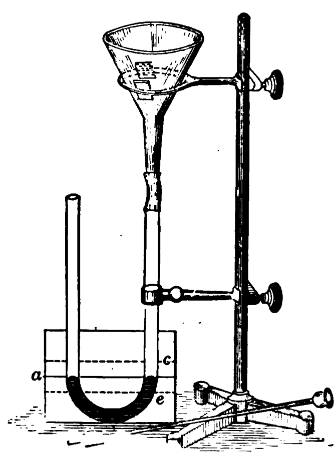

FIG. 60.

equal to the vertical distance between the two dotted lines. The same principle may be strikingly illustrated by using Pascal vases, which may be obtained from dealers in scientific apparatus.

101. Liquid Pressure Due to Gravity. — *The downward pressure caused by the weight of a liquid is independent of the shape of the containing vessel and of the quantity of the liquid. It is proportional to the depth of the liquid and the area of the base.*

Upward Pressure.

Experiment 34. — Make a small hole in the bottom of a tin fruit-can or similar vessel. Push the can downward into water until the open mouth of the can is "near the water's edge." The liquid will spurt upward through the hole in a little jet. Why?

Experiment 35. — Get a lamp-chimney, preferably cylindrical. With a diamond or a steel glass-cutter, cut a disk of window glass a little larger than the cross-section of the lamp-chimney. Pour some fine emery powder on the disk, and rub one end of the chimney upon it, thus grinding them until they fit accurately. With wax, fasten a thread to the center of the ground surface of the disk, and draw that surface against the ground end of the chimney. Holding the chimney in the hand, or supporting it in any convenient way, place it in water as shown in Fig. 61. The upward pressure of the water will hold the disk in place. Pour water carefully into the tube; the disk will fall as soon as the weight of the water in the chimney, plus the weight of the disk, exceeds the upward pressure of the water.

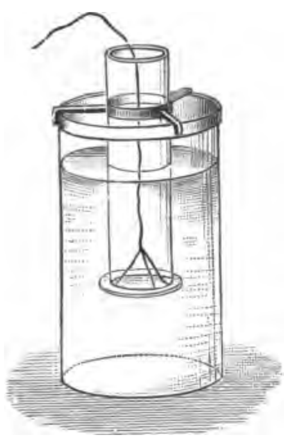

Fig. 61.

102. Rules for Liquid Pressure.

(1) *To find the downward or the upward pressure on any submerged horizontal surface, find the weight of an imaginary*

column of the given liquid, the base of which is the same as the given surface, and the altitude of which is the same as the depth of the given surface below the surface of the liquid.

(2) *To find the pressure upon any vertical surface, find the weight of an imaginary column of the liquid, the base of which is the same as the given surface, and the altitude of which is the same as the depth of the center of the given surface below the surface of the liquid.*

(*a*) A cubic foot of water weighs 62.42 pounds, or about 1,000 ounces.

Liquid Level.

Experiment 36. — To the cork used in Experiment 32, fit a piece of glass tubing about 2 feet long. Holding the chimney on the table-top with this glass tube upright, fill the apparatus with water. Does the water stand at a higher level in the funnel, or in the tube? Raise and lower the funnel, and for each position notice the relation between the liquid levels in the funnel and in the tube.

103. Communicating Vessels. — When a liquid is placed in one or more of several open vessels that communicate with each other, *it will not come to rest until it stands at the same height in all of the vessels.* "Water seeks its level." The principle is illustrated, on a large scale, in the system of pipes by which water is distributed in cities.

EXERCISES.

1. What will be the pressure on a dam in 20 feet of water, the dam being 30 feet long?
2. What will be the pressure on a dam in 6 m. of water, the dam being 10 m. long?
3. Find the pressure on one side of a cistern 5 feet square and 12 feet high, filled with water.
4. Find the pressure on one side of a cistern 2 m. square and 4 m. high, filled with water.
5. A cylindrical vessel having a base of a square yard is filled with water to the depth of two yards. What pressure is exerted upon the base?

6. A cylindrical vessel having a base of a square meter is filled with water to the depth of two meters. What pressure is exerted upon the base?

7. What will be the upward pressure upon a horizontal plate a foot square at a depth of 25 feet of water?

8. What will be the upward pressure upon a horizontal plate 30 cm. square at a depth of 8 m. of water?

9. A square board with a surface of 9 square feet is pressed against the bottom of the vertical wall of a cistern in which the water is $8\frac{1}{2}$ feet deep. What pressure does the water exert upon the board?

10. The lever of a hydraulic press is 6 feet long, the piston rod being 1 foot from the fulcrum. The area of the tube is half a square inch; that of the cylinder is 100 square inches. Find the weight that may be raised by a force of 75 pounds.

11. Cut the bottoms from a large bottle, and from another bottle of about equal height but much less diameter. Close their mouths by corks perforated by bits of glass tubing. Support the bottomless bottles by thrusting their necks downward through two holes bored in the top of a box. With rubber tubing, connect the glass tubes that pass through the corks, making thus two communicating vessels. Half fill the bottles with water, and mark the liquid level on each bottle. Pour a measured quantity of oil into the smaller bottle until it forms a layer several centimeters thick. The water-levels have been changed. Pour measured quantities of the oil into the other bottle until the water is restored to its marked levels. How do the thicknesses of the two oil layers compare? How do the volumes of the two oil layers compare?

Principle of Archimedes.

Experiment 37. — Suspend a stone or a brick by a slender cord or a fine wire from the hook of a spring-balance, and note the reading of the scale. Then immerse the load thus suspended in water and again note the reading. Transfer the load to a strong brine, and note the reading. Transfer the load to kerosene, and note again the reading. It seems as if the liquids help to support the stone, with a force of varying magnitude.

Experiment 38. — From one end of a scale-beam, suspend a cylindrical metal bucket, *b*, with a solid cylinder, *a*, that fits accurately into it hanging below. Counterpoise with weights (shot or sand) in

the opposite scale-pan. Immerse *a* in water, and the counterpoise will descend, as if *a* had lost some of its weight. Carefully fill *b* with water. It will hold exactly the quantity displaced by *a*. Equilibrium will be restored.

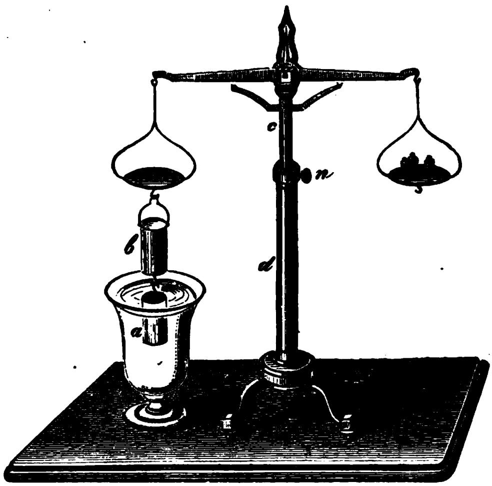

FIG. 62.

Experiment 39. — For rough work, a spring-balance may take the place of the beam-balance; a tin pail may take the place of *b*; a piece of stone suspended beneath the pail by strings tied to the ears of the pail may take the place of *a*; a larger tin pail filled with water and set in a tin pan may take the place of the vessel of water shown in Fig. 62. Note the weight of the smaller pail, with and without the suspended stone. Lower the apparatus so that the stone shall be immersed in the water, and note the reading of the scale. Determine the loss of weight resulting from the immersion of the stone. The volume of water forced from the pail and caught in the pan is equal to what other volume? Remove the pan, immerse the stone as before, pour the water from the pan into the upper pail, and note the reading of the scale. To what other reading is it equal? To what is the weight of the water displaced by the stone equal?

Experiment 40. — Modify the experiment again as follows: Instead of the suspended bucket, *b*, place a tumbler upon the scale-pan. Instead of the cylinder, *a*, suspend any convenient solid heavier than

water, as a potato. Counterpoise the tumbler and the potato with weights in the other scale-pan. Provide an overflow-can by inserting a spout about 6 cm. long and 7 or 8 mm. in diameter in the side of a vessel (as a tin fruit-can) about an inch below the top of the can. This spout should slope slightly downward. Fill the can with water and catch the overflow from the spout in a cup. Throw away the water thus caught. Wait a minute for the spout to stop dripping and then carefully immerse the potato in the water of the can, catching in the cup every drop of water that overflows. Wait a minute for the spout to stop dripping. The equilibrium of the balance is destroyed, but it may be restored by pouring into the tumbler the water that was displaced by the potato and caught in the cup.

104. Archimedes' Principle. — *A body is buoyed up by a force equal to the weight of the fluid that it displaces.* Hence the apparent weight of a body in a fluid (e.g., water or air) is less than its true weight. This buoyant effect is often spoken of as a "loss of weight."

(*a*) When a solid is immersed in a fluid, it displaces its own volume of the fluid. Imagine a solid cube one centimeter on each edge to be immersed in water so that its upper face shall be level and one centimeter below the surface of the liquid, as shown in Fig. 63. The lateral pressures upon any two opposite vertical surfaces of the cube, as *a* and *b*, are clearly equal and opposite. They have no tendency to move the solid. The vertical pressures on the other two faces, *c* and *d*, are not equal. The upper face sustains a pressure equal to the weight of a column of water having a base one centimeter square (i.e., the face, *d*) and an altitude equal to the distance, *dn*. This imaginary column of water has a volume of one cubic centimeter, and a weight of one gram. The downward pressure on *d* is one gram. As the face, *c*, has the same area and is at twice the depth, the upward pressure upon it is two grams. The resultant of the two vertical and opposite forces acting on the cube is an upward pressure of one gram; i.e., the cube is partly supported by

FIG. 63.

a buoyant force of one gram, which is the weight of the cubic centimeter of water that it displaces. No matter what the depth to which the block is immersed, this net upward pressure, or buoyant effect, is always the same.

Flotation.

Experiment 41. — Place the tin can mentioned in Experiment 40 upon one scale-pan, and fill it with water, some of which will overflow through the spout. Do not let any of the water fall upon the scale-pan. When the spout has ceased dripping, counterpoise the vessel of water with weights in the other scale-pan. Place a floating body on the water. This will destroy the equilibrium, but water will overflow through the spout until the equilibrium is restored. This shows that the floating body has displaced its own weight of water.

105. Floating Bodies. — *A floating body will sink in a liquid until it displaces a weight of the liquid equal to its own weight.*

(*a*) When a solid is immersed in a liquid, the buoyant effect of the liquid (§ 104) may exceed the weight of the body; then the body rises to the surface and floats. When buoyancy and weight are equal and opposite, their resultant is zero, and the body is in equilibrium in any part of the liquid. When the weight exceeds the buoyancy, the body sinks. In any case, Archimedes' principle is strictly true.

EXERCISES.

1. How much weight will a cubic decimeter of iron lose when placed in water?

2. How much weight will it lose in a liquid 13.6 times as heavy as water?

3. If the cubic decimeter of iron weighs only 7,780 g., what does your answer to Exercise 2 signify?

4. How much weight will a cubic foot of stone lose in water?

5. If 100 cu. cm. of lead weighs 1,135 g., what will it weigh in water?

6. If a brass ball weighs 83.8 g. in air, and 73.8 g. in water, what is its volume?

7. A cubical vessel 20 cm. on an edge has fitted into its top a tube 2 cm. square and 10 cm. high. Box and tube being filled with water, (*a*) what is the weight of the water? (*b*) What is the liquid pressure on the bottom of the vessel? (*c*) If the weight and pressure differ, explain the difference.

106. Density. — *The density (or specific gravity) of a substance is the ratio between the weight of any volume of the substance and the weight of a like volume of some other substance taken as a standard.* For solids and liquids, the standard is distilled water at its temperature of maximum density (4° C. or 39.2° F.); for gases and vapors, the standards are hydrogen and air, each under a barometric pressure of 76 centimeters, and at the temperature of 0° C. The term "density" has nearly displaced "specific gravity" in scientific works.

(*a*) To illustrate, in the simplest way, what is meant by density, suppose that 1 cu. cm. of marble weighs 2.7 g. Since 1 cu. cm. of water weighs 1 g., the marble is 2.7 times as heavy as water, volume for volume. In shorter phrase, the density of marble is 2.7. To avoid the difficulty of obtaining just a unit volume of the substance, the principle of Archimedes is utilized, as will be illustrated.

107. To Find the Density of a Solid Heavier than Water. — The most common way of determining the density of such a body, if it is insoluble in water, is to find its weight in air (w); find its weight when immersed in water (w'); divide the weight in air by the loss of weight in water.

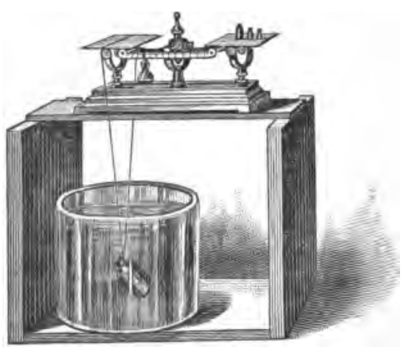

FIG. 64.

$$D = \frac{w}{w - w'}.$$

(*a*) This method is illustrated by the following example: —

(1)	Weight of the solid in air	(w)	113.4 g.
(2)	" " " " " water	(w')	79.14 g.
(3)	" " equal bulk of water	($w - w'$) ...	34.26 g.
(4)	Density " the solid (1) ÷ (3)		3.31

(*b*) Hydrometers are convenient for this purpose. Some of them are of constant volume, and others are of constant weight. The Nicholson hydrometer of constant volume is a hollow cylinder carrying at its lower end a basket, d, heavy enough to keep the apparatus upright in water. At the top of the cylinder is a vertical rod carrying a pan, a, for holding weights, etc. The whole apparatus must be lighter than water, so that a certain weight (W) must be put into the pan to sink the apparatus to a fixed point marked on the rod (as c). The given body, which must weigh less than W, is placed in the pan, and enough weights (w) added to sink the point, c, to the water-line. It is evident that the weight of the given body is $W - w$. The given body is now taken from the pan and placed in the basket, when additional weights, x, must be added to sink the point, c, to the water-line.

FIG. 65.

$$D = \frac{W - w}{x}.$$

108. To Find the Density of a Solid Lighter than Water. — Fasten to it another body heavy enough to sink it in water. Find the loss of weight for the combined mass when weighed in the water. Do the same for the heavy body. Subtract the loss of the heavy body from the loss of the combined mass. Divide the weight of the given body by this difference.

109. To Find the Density of a Solid Soluble in Water. — Determine the density of the given solid with reference to some liquid, the density (d) of which is known, and in which the solid is not soluble. Multiply the result (obtained by any of the processes previously described) by the density of the liquid used.

$$D = \frac{wd}{w - w'}.$$

110. To Find the Density of a Liquid. — There are several methods of finding the density of a liquid, but the principle in each is that already given.

(*a*) Four of these methods are given here; others will be found in the Exercises.

(1) Weigh a flask, first, empty; next, full of water; then, full of the given liquid. Subtract the weight of the empty flask from the other two weights; the results represent the weights of equal volumes of the given substance and of the standard. Divide as before. A flask of known weight, graduated to measure 100 or 1,000 grams or grains of water, is called a *specific-gravity flask.* Its use avoids the first and second weighings above mentioned, and simplifies the work of division.

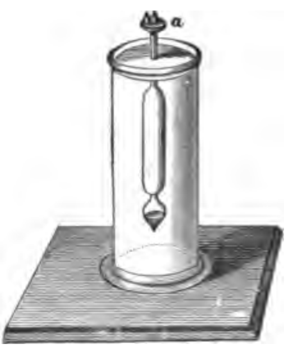

FIG. 66.

(2) Find the loss of weight of any insoluble solid in water and in the given liquid. Divide the latter loss by the former. A solid thus used is called a *specific-gravity bulb.*

(3) The Fahrenheit hydrometer of constant volume is made of glass, the bulb at the bottom being loaded with mercury or shot. Its weight (W) being accurately determined, the instrument is placed in water, and a weight (w) sufficient to sink a marked point on the rod to the water-line is placed in the pan. The weight of water displaced by the instrument $= W + w$. The hydrometer is then removed, wiped dry, and placed in the given liquid. A weight (x) sufficient to sink the hydrometer to the marked point is placed in the pan. (Fig. 66.)

$$D = \frac{W + x}{W + w}.$$

FIG. 67.

(4) As generally made, a hydrometer of constant weight consists of a glass tube near the bottom of which are two bulbs. The lower and smaller bulb is loaded with mercury or shot. The tube and upper bulb contain air. The point to which it sinks when placed in water is

marked zero. The tube is graduated, the scale being arbitrary, and varying with the purpose for which the instrument is intended. Such hydrometers are used to determine the degree of concentration of certain liquids, as acids, alcohols, milk, solutions of sugar, etc. According to their uses they are known as *acidometers, alcoholometers, lactometers, saccharometers,* etc. (Fig. 67.)

NOTE. — The density of an aëriform body is found by comparing the weights of equal volumes of the standard (air or hydrogen) and of the given substance. The method is much like that first given for liquids. The determination of the density of gases presents many practical difficulties which cannot be considered in this place.

111. Water Power. — An elevated body of water is a storehouse of potential energy. As the water runs to a lower level, it may be made to turn a wheel, and thus to move machinery, etc., a good illustration of the conversion of potential into kinetic energy.

(*a*) Water-wheels are of different kinds, their relative advantages depending upon the nature of the water-supply and of the work to be done.

EXERCISES.

NOTE. — Be on the alert to recognize Archimedes' Principle in disguise. Consider the weight of water 62½ pounds per cubic foot.

1. A piece of metal weighing 52.35 g. in air is placed in a cup filled with water. The overflowing water weighs 5 g. What is the density of the metal?

2. A solid weighing 695 g. in air loses 83 g. when weighed in water. What is its density?

3. A 1,000-grain bottle holds 708 grains of benzoline. Find the density of the benzoline.

4. A solid that weighs 2.4554 ounces in air, weighs only 2.0778 ounces in water. Find its density.

5. A specimen of gold that weighs 4.6764 g. in air, loses 0.2447 g. weight when weighed in water. Find its density.

6. A ball weighing 970 grains, weighs in water 895 grains, in alcohol 910 grains. Find the density of the alcohol.

7. Calculate the density of sea water from the following data:—

Weight of bottle empty	3.5305 g.
" " filled with distilled water . .	7.6722 g.
" " " sea " . .	7.7819 g.

8. Determine the density of a piece of wood from the following data: weight of wood in air, 4 g.; weight of sinker, 10 g.; weight of wood and sinker under water, 8.5 g.; density of sinker, 10.5.

9. A lump of ice weighing 8 pounds is fastened to 16 pounds of lead. In water, the lead alone weighs 14.6 pounds, while the lead and ice weigh 13.712 pounds. Find the density of the ice.

10. A weight of 1,000 grains will sink a certain Nicholson hydrometer to a mark on the rod carrying the pan. A piece of brass plus 40 grains will sink it to the same mark. When the brass is taken from the pan and placed in the basket, it requires 160 grains in the pan to sink the hydrometer to the same mark on the rod. Find the density of the brass.

11. A Fahrenheit hydrometer, which weighs 2,000 grains, requires 1,000 grains in the pan to sink it to a certain depth in water. It requires 3,400 grains in the pan to sink it to the same depth in sulphuric acid. Find the density of the acid.

12. A hollow ball of iron weighs 1 Kg. What must be its least volume to float on water?

13. Rock-salt is soluble in water, and insoluble in naphtha. Determine the density of a specimen of rock-salt.

14. Make a rod of white pine or other light wood, just 1 cm. square and about 30 cm. long. In one end, bore a hole, and pound in enough sheet lead to make the rod stand on end when floated in water and with about half of it immersed. Fill the rest of the cavity with putty, and dip the rod into hot paraffin. Graduate one side of the rod to millimeters, with the zero of the scale at the loaded end. Place the rod in water, and read from the scale the depth to which it sinks. Using it as a hydrometer of constant weight, determine the density of alcohol, and of a 20-per-cent solution of common salt.

15. Paste a strip of writing paper around the upper end of the rod used in Exercise 14, one edge of the paper overlapping the end of the stick so as to make a small cup. Float the rod as before, and place enough shot or sand in the cup to bring one of the graduations exactly to the water-level. Add successively weights of 1 g., 2 g., 3 g., etc., and at each addition, note how much the rod sinks. Record the teachings of the experiment.

16. Provide a bottle that will hold two or three ounces of water, and that has a ground-glass stopper; a thread with which to suspend the bottle; a cloth with which to wipe the bottle; a delicate spring-

balance; water; kerosene. Without any other apparatus or supplies, determine the density of the kerosene.

17. Fill a bottle like that used in Exercise 16 with water, and put the stopper firmly into place. Without removing the stopper or adding to your material, determine the density of the kerosene.

18. Get a glass U-tube with an internal diameter of 8 or 10 mm. and having arms that are close together and about 50 cm. long (see Fig. 60); a meter stick graduated to millimeters; a small funnel for pouring liquids into the U-tube; some support that will hold the U-tube upright; water; kerosene. Without additional material, determine the density of the kerosene.

VIII. THE MECHANICS OF GASES.

112. Pneumatics *is the branch of physics that treats of the mechanical properties of gases*, and describes the machines that depend for their action chiefly on the pressure and elasticity of air.

(*a*) As water was taken as the type of liquids, so atmospheric air will be taken as the type of gases. All statements made in Section VII. concerning fluids, apply to gases as well as to liquids.

NOTE. — It is taken for granted that the school has an air-pump, an instrument that will soon be described, and the simpler pieces of apparatus that generally accompany it.

Weight of Air.

Experiment 42. — On a delicate balance, carefully weigh a thin glass or metal vessel that will hold several liters, and that may be closed by a stopcock. Pump the air from the vessel, close the stopcock, remove the vessel from the pump and carefully weigh it again. Its loss of weight measures the weight of the air removed.

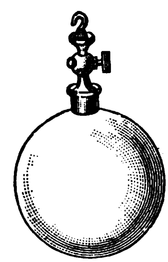

FIG. 68.

Experiment 43. — Fill a tumbler with water, place a slip of thick paper over its mouth and hold it there while the tumbler is inverted;

FIG. 69.

the water will be supported when the hand is removed from the card.

Experiment 44. — To the lamp-chimney apparatus used in Experiment 32, connect a thick-walled rubber tube, and partly exhaust the air with the air-pump or by suction. Hold the chimney in different positions, and notice that the pressure that pushes in the rubber diaphragm is exerted equally in all directions. Any change of pressure will be shown by a change in the form of the rubber cup.

Experiment 45. — The Magdeburg hemispheres are accurately fitting, metallic vessels, generally three or four inches in diameter. Their edges are provided with projecting lips, and fit one another air-tight; the lips prevent sidewise slipping. Grease the edges to make sure of a tight joint, fit the hemispheres to each other, and exhaust the air with a pump. Close the stopcock, remove the hemispheres from the pump, attach the second handle, and, holding the hemispheres in different positions, try to pull them apart. When you are sure that the pressure that holds them together is exerted in all directions, place them under the receiver (i.e., the bell-glass) of the air-pump, and exhaust the air from around them. The pressure seems to be removed, for the hemispheres fall apart of their own weight.

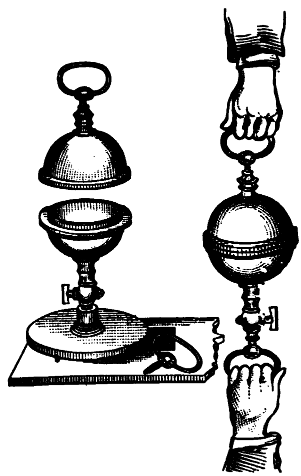

FIG. 70.

113. The Air. — *These experiments show that air has weight, that it exerts great pressure at the surface of the earth, and that this pressure is transmitted equally in all directions.* Under ordinary conditions, a liter of air weighs about 1.3 grams; a cubic foot weighs about an ounce and a quarter.

Atmospheric Pressure.

Experiment 46. — Into one end of a piece of stout glass tubing about 1 m. long, and with a bore of about 1 cm., closely press a good cork or rubber stopper. Fill the tube with water; close the open end with the forefinger; invert the tube over the water-bath, and, when the end is under water, remove the finger. Note whether the water falls away from the corked end of the tube. Loosen or remove the cork, and note the result.

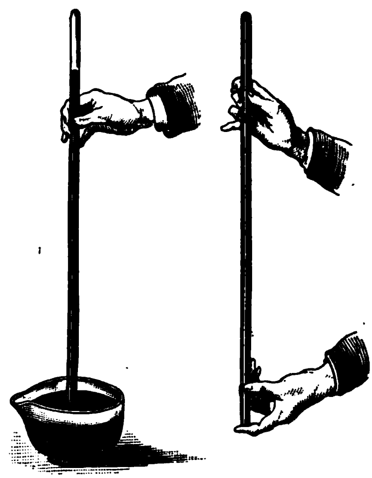

FIG. 71.

Experiment 47. — Fill with mercury a stout glass tube closed at one end and about 50 cm. long; a long "ignition tube" will answer. Invert it at the mercury-bath as shown in Fig. 71. Note whether the mercury falls away from the closed end of the tube.

Experiment 48. — Select a stout glass tube about 80 cm. long, several millimeters in internal diameter, and closed at one end. Twist a piece of paper into the shape of a hollow cone, and using it as a funnel, fill the tube with mercury. With an iron wire, remove any air-bubbles that you see in the tube. Close the open end with the finger, and invert the tube at the mercury-bath, as shown in Fig. 71. When the finger is removed, the mercury falls away from the upper end of the tube, and finally comes to rest at a height of about 30 inches (or 76 cm.) above the level of the mercury in the bath, leaving a vacuum at the upper end of the tube. This is known as Torricelli's Experiment.

Experiment 49. — Modify the last experiment by selecting a tube open at both ends. Thoroughly soak in water such a membrane as comes tied over the stoppers of perfume bottles, and tie it tightly over one end of the tube. When the membrane is thoroughly dry, fill the tube with mercury, and invert it at the mercury-bath as before. After measuring the height of the supported liquid column, prick a pinhole through the membrane, and notice what takes place.

114. Atmospheric Pressure. — *These experiments show that the pressure of the atmosphere may support a liquid column of great weight. This pressure at the sea-level is approximately* 1,033.3 *grams per square centimeter, or* 14.7 *pounds per square inch.* For rough work or "in round numbers," it is often said that this pressure, which is called an atmosphere, is a kilogram per square centimeter, or fifteen pounds per square inch.

(*a*) Pascal carried a Torricellian tube (see Experiment 48) to the top of a mountain, and there found that the mercury column was three inches shorter, showing that, as the weight of the atmospheric column diminishes, the counterbalanced column of mercury also diminishes.

115. The Barometer. — *A Torricellian tube, firmly fixed to an upright support and properly graduated, constitutes a mercurial barometer.* The zero of the scale is at the surface of the mercury in the cistern.

FIG. 72.

(*a*) When scientific accuracy is required, the height of the barometer is corrected for temperature, for variations of gravity, for capillarity, for expansion of the scale, for elevation above sea-level, etc.

(*b*) Observation shows frequent variations in the barometric readings. Some slight changes are found to be periodic, but the greater changes follow no known law. *The utility of a barometer depends largely upon the fact that these irregular variations correspond to changes in the atmospheric pressure, and, therefore, signal coming meteorological changes.* The falling of the mercury generally indicates the approach of foul weather; a sudden fall denotes the coming of a storm. The rising of the mercury indicates the approach of fair weather or the "clearing up" of a storm.

EXERCISES.

1. Give the pressure of the air upon a man the surface of whose 20 square feet.

2. What is the weight of the air in a room 30 by 20 by 10 feet?

3. How much weight does a cubic foot of wood lose when weighed in air?

4. (*a*) What is the pressure on the upper surface of a Saratoga trunk 2½ by 3½ feet? (*b*) How happens it that the owner can open the trunk?

5. (*a*) What effect would it have upon the height of the barometric column if the barometer tube was enlarged until it had a sectional area of 1 sq. cm.?

6. An empty toy balloon weighs 5 g. When filled with 10 l. of hydrogen, what load can it lift? A liter of hydrogen weighs 0.0896 g.

Elastic Force.

Experiment 50. — Tightly close the opening of a toy balloon, football, or other rubber bag, only partly filled with air. Place it under the receiver of an air-pump, as shown in the accompanying figure, and exhaust the air from the receiver. The flexible wall of the bag will be pushed back by the innumerable impacts of the moving molecules against the confining surface. The observed phenomenon is in strict accord with the kinetic theory of gases, § 36.

FIG. 73.

Experiment 51. — For the rubber bag used in Experiment 50, substitute successively a dish containing soap-bubbles, and a bottle with its mouth opening under water in a tumbler. Exhaust the air as before, and notice the effect of the molecular impacts on the liquid walls of the confined air.

116. Elastic Force of Gases. — *The elastic force of a gas supports and equals the pressure upon it.*

Relation of Volume to Pressure.

Experiment 52. — Provide two glass tubes connected by stout rubber tubing and carried by a vertical stand as shown in Fig. 74. The left-hand tube, *B*, may be about 30 cm. long and 5 mm. in diameter, and must be closed at the upper end. The right-hand tube, *C*, should be of greater diameter, open at the upper end, and arranged so that it may slide up and down by the side of the vertical scale. Pour mercury

into *C*, thus confining in *B* a quantity of air on which the experiment is to be made. The volume of this confined air under varying pressure will be proportional to the length of the tube which it occupies. Slide *C* up or down until the mercury stands at the same level in *B* and *C*. The air confined in *B* is under a pressure of one atmosphere. Read directly from the scale the length of the tube that it occupies and make a record of it. For the sake of illustration, suppose that it occupies 5 spaces. Note the reading of the barometer at the time of the experiment; suppose this to be 76 cm. Make the record that the confined air, under a pressure of 76 cm. of mercury, occupies 5 volumes. Then raise *C*, thus increasing the pressure on the air in *B*. When the vertical distance between the levels of the mercury in *B* and *C* is one-fourth the height of the barometric column, the pressure upon the confined air will be $\frac{5}{4}$ atmospheres, or 95 cm. of mercury; the elastic force of the confined air just supports this pressure, and must, therefore, be $\frac{5}{4}$ atmospheres. Reading from the scale, it will be seen that the confined air measures only 4 volumes; i.e., $\frac{4}{5}$ as much as it did under a pressure of one atmosphere. Then raise *C* until the vertical distance between the two surfaces of the mercury is half the height of the barometric column; the confined air is under a pressure of $\frac{6}{4}$ atmospheres (114 cm.); its volume is $\frac{4}{6}$ what it was under a pressure of one atmosphere, i.e., $3\frac{1}{3}$ volumes. Again, raise *C* until the vertical distance between the two surfaces of the mercury is equal to the height of the barometric column; the confined air is now under a pressure of two atmospheres (152 cm.); its volume is $\frac{1}{2}$ what it was under a pressure of one atmosphere, i.e., $2\frac{1}{2}$ volumes. Arrange the data in the following form, and complete the table:—

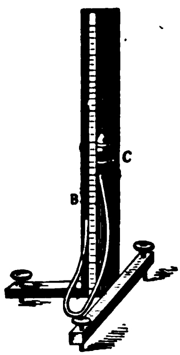

FIG. 74.

Pressures.	*Volumes.*	*Products.*
76	5	380
95	4	?
114	$3\frac{1}{3}$	?
152	$2\frac{1}{2}$	?

117. Boyle's Law.—When the temperature remains constant, *the volume of a gas varies inversely as the pres-*

sure upon it; i.e., the product of the volume of the gas by its pressure is constant.

(*a*) Later experiments have shown that Boyle's law is only approximately true, and that all gases deviate from it as they near the point of liquefaction. This law is often called Mariotte's.

EXERCISES.

1. Under ordinary conditions, a certain quantity of air measures one liter. Under what conditions can it be made to occupy (*a*) 500 cu. cm.? (*b*) 2,000 cu. cm.?

2. Into what space must we compress (*a*) a liter of air to double its elastic force? (*b*) Two liters of hydrogen?

3. A barometer standing at 30 inches is placed in a closed vessel. How much of the air in the vessel must be removed that the mercury may fall to 15 inches?

4. A vertical tube, closed at the lower end, has at its upper end a frictionless piston that has an area of 1 square inch. The weight of this piston is 5 pounds, and it confines 24 cubic inches of dry steam. (*a*) What is the elastic force of the confined steam? (*b*) If the piston is loaded with a weight of 10 pounds, what will be the volume of the confined steam?

5. Mercury stands at the same level in both arms of the apparatus shown in Fig. 74. The barometer rises, and thereupon is noticed a difference in the heights of the two mercury columns. In which arm does the mercury stand the higher? Why?

Siphon.

Experiment 53. — Place a pail of clean water on the table, and an empty water pail on the floor. Place one end of a piece of thick-walled rubber tubing, about a yard long, in the water. Hold the other end of the tubing below the level of the table-top, and fill the tube with water by suction. Notice the transfer of water from one pail to the other. Be careful that the flexible walls of the tubing do not close upon each other at the edge of the upper pail, and thus cut off the flow.

Experiment 54. — Change the positions of the pails, placing the one containing water on the table. Gradually lower the rubber tubing into the water, allowing air to escape from the upper end as water

enters at the lower end. When the tube is filled with water, pinch one end of it tightly, and carry it below the level of the table-top. Raise and lower this end of the tubing to see if the distance of the opening below the edge of the upper pail has anything to do with the rate of flow.

118. The Siphon *is essentially a tube with unequal arms, used to carry liquids from one level, over an elevation, to a lower level by means of atmospheric pressure.* The flow will continue until the liquids stand at the same level, or until air enters the tube at the end of the shorter arm.

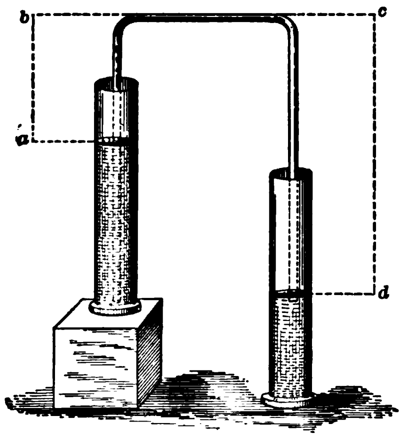

FIG. 75.

(*a*) The vertical distance from the level of the upper liquid to the highest point of the tube (*ab*) is the length of one arm; the vertical distance from the highest point of the tube to the lower end of the tube, or to the level of the liquid into which it dips (*cd*), is the length of the other arm. The second of these must exceed the first.

Consider the horizontal layer of molecules in the tube at the levels, a and d. The atmospheric pressures, whether direct or transmitted by the liquids in accordance with Pascal's law, will be upward and equal; represent them by p. The weight of the water in the short arm produces a downward pressure at a; represent this by w. The resultant of these forces acting at a is $p - w$. Similarly, the weight of the water in the long arm produces a downward pressure at d; represent this by w'. The resultant of these forces acting at d is $p - w'$. These two resultants act against each other, $p - w$ being the greater. The resultant of these resultants is their difference; $(p - w) - (p - w') = w' - w$. Thus we see that the liquid is pushed through the tube by a resultant force equal to the weight of a liquid

column whose height is the difference between the two arms of the siphon.

(*b*) If the downward liquid pressure at *a* is as great as the atmospheric pressure, the liquid will not flow. Hence, the elevation over which water is to be siphoned must be less than 34 feet.

Pumps.

Experiment 55. — Every one knows that a liquid may be sucked up through a straw or other tube. Modify the familiar experiment by passing a glass tube snugly through the cork of a bottle. Fill the bottle with water, and close it with the perforated cork. Be sure that no air is left in the bottle. The tube should dip an inch or so into the water. Try to suck water from the bottle.

119. The Lift Pump or suction-pump consists of a cylinder or barrel, a piston, two valves, and a suction-pipe, the lower end of which dips below the surface of the liquid to be raised. The piston works practically air-tight in the cylinder, and has an outlet-valve that opens upward. The inlet-valve is at the upper end of the suction-pipe, and also opens upward.

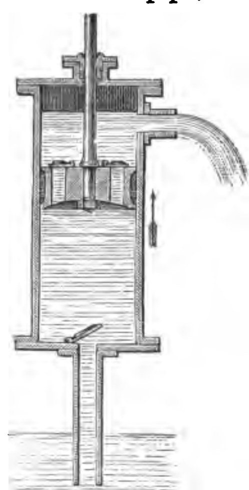

FIG. 76.

(*a*) When the piston is drawn upward, its valve is closed by the pressure of the air above, and a partial vacuum is formed in the cylinder below. The elastic force of the air in the cylinder being thus reduced, *the atmospheric pressure forces water up the suction-pipe*, driving the air above it through the lower valve. When the piston is pushed down, the inlet-valve is closed, and the confined air escapes through the outlet-valve. As the piston continues its work, the air is gradually removed from the cylinder and suction-pipe, and the transmitted pressure of the atmosphere pushes the water up to take its place and to restore the disturbed equilibrium. Owing to mechanical imperfections, the practical limit for a pump lifting water by suction is about 28 vertical feet.

120. The Force Pump. — The operation of the force-pump is similar to that of the suction-pump. The outlet-valve generally opens from the cylinder, the piston being made solid, as shown in the accompanying figure.

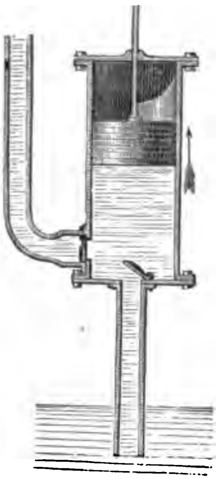

FIG. 77.

(*a*) When the piston is forced down, the inlet-valve is closed, the water being forced through the other valve into the discharge-pipe. When next the piston is raised, the outlet-valve is closed, preventing the return of the water above it, while atmospheric pressure forces more water from below into the barrel.

For the purpose of securing steadiness for the stream as it issues from the delivery-pipe, the water usually passes into an air-chamber. The elasticity of the confined and compressed air largely takes up the pulsating effect due to the successive pushes of the piston, and forces the water from the nozzle of the delivery-pipe in a continuous stream.

121. The Air Pump is an instrument for removing a gas from a closed vessel. Figure 78 shows the essential parts of one of the many forms.

(*a*) The glass receiver, *R*, fits accurately upon the ground plate. The edge of the receiver is often greased to insure an air-tight joint. The inlet-valve, *v*, may be carried by a rod that passes through the piston, *P*. The outlet-valve, *v′*, is in the piston. Of course, the valves and all sliding parts must work air-tight. A down-stroke of the piston carries down the valve-rod, and closes *v*; the elastic force of the air in *C* opens *v′*, and some of the confined air escapes. The next up-stroke of the piston closes *v′*, lifts the valve-rod, and opens *v*. The upward motion of the valve-rod is closely limited by a shoulder near its upper end, the piston sliding upon the rod during the greater part of its up-and-down movements. The air that passes up through *v′* is forced out through an opening (preferably closed by a valve) at the top of the cylinder. The air in *t* and *R* is thus gradually removed. As only a fractional part of this residual air is removed at each

stroke, a perfect vacuum is out of the question; moreover, there is a limit arising from the unavoidable imperfections of the apparatus. The glass vessel, *F*, contains a gauge to indicate the degree of rarefaction obtained. A stopcock at *S*, when turned one way, cuts off communication between *C* and *R*, thus reducing the risk that air will reënter the receiver; when turned the other way, it readmits air to *R*.

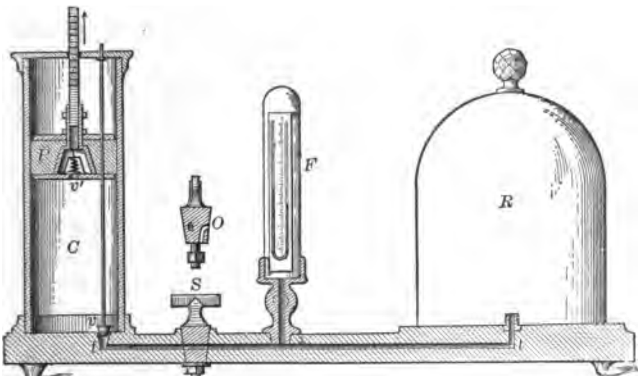

FIG. 78.

122. The Condensing Pump is an instrument for compressing a gas into a closed vessel, as in pumping air into a pneumatic tire of a bicycle.

(*a*) It differs from the air-pump chiefly in that the valves are made strong enough to endure high pressures, and that they open toward the receiver.

EXERCISES.

1. If a lift-pump can just raise water 28 feet, how high can it raise alcohol having a density of 0.8?

2. Water is to be taken over a ridge 12.5 m. higher than the surface of the water. (*a*) Can it be done with a siphon? Why? (*b*) With a lift-pump? Why? (*c*) With a force-pump? Why?

3. Will a given siphon carry water over a given elevation more rapidly at the top, or at the bottom, of a mountain? Why?

4. The "sucker" consists of a circular piece of

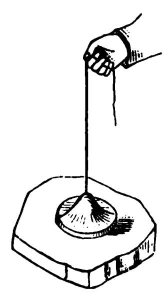

FIG. 79.

thick leather with a string attached to its middle. Being soaked thoroughly in water, it is firmly pressed upon a flat stone to drive out all air from between the leather and the stone. Unless the stone is too heavy, it may be lifted by the string. Is the stone really pulled up, or pushed up? Explain your answer.

5. Partly fill two bottles with water. Connect them by a bent tube that fits closely into the mouth of one, and loosely into the mouth of the other. Place the bottles under the receiver of the air-pump, and exhaust the air. Note and record what takes place. Admit air to the receiver. Note and record what takes place. Write an explanation of the phenomena.

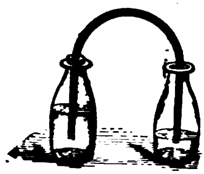

FIG. 80.

6. Fill a test-tube with water and invert it in a tumbler of water. With a pen-filler, introduce a few drops of sulphuric ether, a very volatile and extremely inflammable liquid, into the test-tube. The ether will rise to the top of the tube. Place the tumbler and the test-tube under the receiver and exhaust the air. The water in the test-tube falls. Readmit air to the receiver, and note the contents of the test-tube. Record your conclusions concerning the effect of pressure upon the molecular condition of sulphuric ether.

7. With a short piece of rubber tubing, connect the short arms of two L-shaped glass tubes, and set up the apparatus as a siphon. While the water is flowing, perforate the rubber wall between the glass tubes. Note and explain the effect.

CHAPTER III.

ACOUSTICS: MASS PHYSICS.

I. THE NATURE OF SOUND, ETC.

123. Sound *is a mode of motion that is capable of affecting the auditory nerve.*

Cause of Sound.

Experiment 56.—Sound a tuning-fork and just touch a water surface with one of its prongs. Notice the spray.

Experiment 57.—Grasp one end of a straight spring made of hickory or steel in one end of a vise, as shown in Fig. 81. Pluck the free end of the spring so as to produce a vibratory motion. If the spring is long enough, the vibrations may be seen. Lower the spring in the vise to shorten the vibrating part of the rod, and pluck it again. The vibrations are reduced in amplitude, and increased in rapidity. Continued shortening of the spring will render the vibrations invisible and audible; they are lost to the eye, but revealed to the ear.

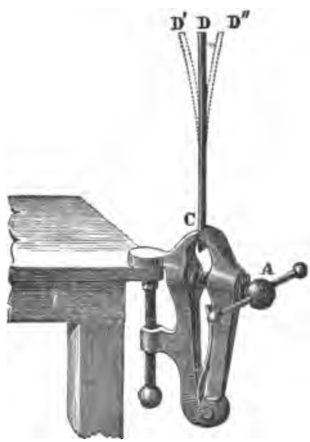

FIG. 81.

124. Sound *is caused by the rapid vibrations of a material body.* All sounds may be traced to such vibrations. Bodies that emit sounds are called sonorous.

Wind or Wave?

Experiment 58.—Provide a tube four or five yards long, and about four inches in diameter. A few lengths of common spout from the tinner's will answer. Furnish it with a funnel-shaped piece, having an opening about an inch in diameter. Place the tube on a table with a candle flame opposite the opening at *B*. With a book, strike a

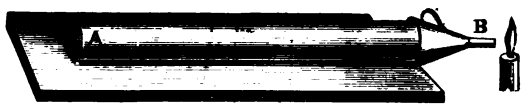

FIG. 82.

sharp blow upon the table opposite the opening at *A*. The flame will be agitated and perhaps blown out. Something went from *A* to *B*. Did it go through the tube?

Experiment 59.—Close the opening at *A* and repeat the experiment; the flame is not put out. Remove the tube and repeat the blow; the flame is not put out.

Experiment 60.—Dissolve as much potassium nitrate (saltpeter) as you can in half a cupful of hot water. Soak a piece of blotting-paper in this liquid and dry it. This "touch-paper" burns with much smoke but no flame. Burn the paper in the tube near *A*, filling that end of the tube with smoke. Repeat Experiment 58. No smoke issues at *B*; *it was not a wind that passed through the tube.*

125. Propagation of Sound.—Sound is ordinarily propagated through the air. Tracing the sound from its source to the ear of the hearer, we may say that the first layer of air is struck by the vibrating body. The particles of this layer give their motion to the particles of the next layer, and so on until the particles of the last layer strike upon the drum of the ear.

(*a*) This idea is beautifully illustrated by Professor Tyndall. He imagines five boys placed in a row, as shown in Fig. 83. "I suddenly push *A*; *A* pushes *B* and regains his upright position; *B* pushes *C*; *C* pushes *D*; *D* pushes *E*; each boy, after the transmission of the push, becoming himself erect. *E*, having nobody in front, is thrown

forward. Had he been standing on the edge of a precipice, he would have fallen over; had he stood in contact with a window, he would have broken the glass; had he been close to a drumhead, he would have shaken the drum. We could thus transmit a push through a row of a hundred boys, each particular boy, however, only swaying to and fro. Thus also we send sound through the air, and shake the drum of a distant ear, while each particular particle of the air concerned in the transmission of the pulse makes only a small oscillation."

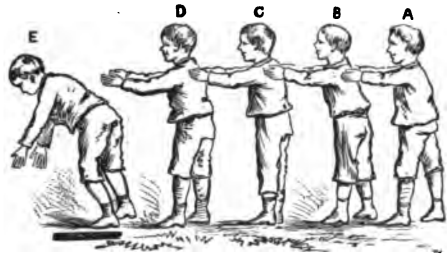

FIG. 83.

The Medium of Sound.

Experiment 61. — Provide a wooden rod about half an inch square and five or six feet long. Place one end of this rod (preferably made of light, dry pine) against the panel of a door; hold the rod horizontal, and place the handle of a vibrating tuning-fork against the other end. Notice the sound given out by the panel. The common "string telephone" is a more familiar illustration of the transmission of sound by a solid.

126. Sound Media. — *Any elastic substance may be the medium for the transmission of sound.* Liquids and solids are better conductors of sound than gases are. The scratching of a pin may be heard through a long wooden beam; and the gentle tap of a hammer, through a water-pipe a mile or more in length.

Vibratory Motion.

Experiment 62. — Grip one end of the meter stick in a vise, as shown in Fig. 81. Pluck the free end, and notice that the vibrating end returns periodically to the starting point. Suspend a lead bullet by a long thread, swing it as a pendulum, and notice that the ball returns periodically to the starting point. Swing the ball as a conical

pendulum, and notice that the ball, moving in a circular path, returns periodically to the starting point.

Experiment 63. — Fasten an elastic cord to a ball, or buy a "return ball" at a toy shop. Hold the end of the cord in one hand, and, with the other hand, pull the ball down and let it go. The ball swings up and down in the direction of the length of the cord. Notice that the speed of the ball varies much as does that of a common pendulum, and that the ball returns periodically to the starting point.

127. Vibrations. — When the parts of a body move so that each returns periodically to its initial position, the body is said to be in vibration. ***The motion made in the interval between two successive passages in the same direction through any position is called a vibration.***

(*a*) A vibration corresponds to a double or "complete" oscillation. When the movement is comparatively slow, as that of a pendulum, the term "oscillation" is commonly used; the term "vibration" is generally confined to rapid movements, like those of a sounding body.

Pendular Motion.

Experiment 64. — Let a pupil take a ball-and-thread pendulum to the further side of the room, and swing the ball in a circular path, thus forming a conical pendulum. When the speed of the ball has become uniform, count the swings that the ball makes around the circle in 30 seconds. Then place your eye on a level with the ball and observe it; i.e., look at the ball along a line of sight that is in the plane of the circle. *The ball will appear to move from side to side in a straight line that coincides with a diameter of the circle, and to vary its velocity as a common pendulum does.* Next, swing the same ball as a common pendulum, and count the vibrations that it makes in 30 seconds. A conical pendulum and a common pendulum of the same length have the same period. When the common pendulum is viewed from beneath, i.e., when the line of sight is in the plane of vibration as before, the ball again appears to move in a straight line and with a

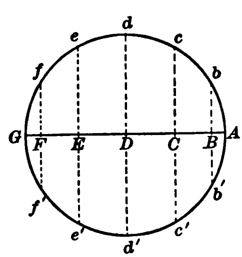

FIG. 84.

like varying velocity. This apparent motion and its relation to the real motion are very interesting and instructive. Let the circle shown in Fig. 84 represent the path described by the conical pendulum; then will the diameter, AG, represent the apparent rectilinear path. Suppose that the ball goes around the circle in two seconds. Divide the circumference into any number of equal parts, as 12. The ball will move over each of these equals arcs in $\frac{1}{6}$ of a second. To one who is looking at this motion in the plane of the paper, the ball appears to go from A to B while it really goes from A to b; it appears to go from B to C while it really goes from b to c; etc. When the ball is at d, it is moving across the line of sight, and, therefore, appears to have its greatest velocity, just as a common pendulum does, at the middle of its arc. When it is at A or G, it is moving in the line of sight, and, therefore, appears to be at rest, although it is really moving with its uniform velocity. From a study of the figure, it will be seen that the ball appears to go from A to G and back in the two seconds in which it really goes around the circle. The unequal lengths, AB, BC, . . . FG, give a fair idea of the varying speed of a common pendulum.

128. Simple Harmonic Motion. — If, while a particle moves in the circumference of a circle with uniform velocity, a point moves along a fixed diameter of the circle so as always to be at the foot of a perpendicular drawn from the particle to the diameter, as described in Experiment 64, the motion of the point along the diameter is called a *simple harmonic motion*. The radius of the circle, or the distance from the middle to the extremity of the swing, is called the *amplitude* of vibration; the time intervening between two passages of the particle in the same direction through any point is called the *period* of vibration.

Transverse Waves.

Experiment 65. — Drop a pebble into a tub of water. Waves will be seen moving on the surface of the water from the center of disturbance, and in concentric circles, toward the sides of the tub. A small cork floating on the surface rises and falls with the water, but is not carried along by the advancing waves of troughs and crests.

Experiment 66. — Tie one end of a soft cotton rope about 20 feet long to a fixed support, and hold the other end in the hand. Move the hand up and down with a quick, sudden motion, so as to set up a

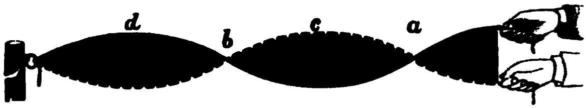

FIG. 85.

series of waves in the rope, as shown in Fig. 85, in which each curved line may be considered an instantaneous photograph of a rope thus shaken.

129. Waves of Crests and Troughs. — In the familiar waves of water, ropes, carpets, etc., the motion of each material particle is vibratory, not progressive; to and fro across the line in which the wave advances, i.e., transverse. It is also a simple harmonic motion. *The only thing that has an onward movement is the wave, which is only a form or change in the relative positions of the particles of the undulating substance.*

(*a*) By fixing a pencil at the end of a lath firmly held at the other end, and vibrating in a horizontal plane, the pencil may be made to mark a nearly straight line, *ab*, on a sheet of paper or cardboard. By moving the paper while the rod is vibrating, the pencil may be made to trace a sinusoidal curve or wavy line like that shown in Fig. 86.

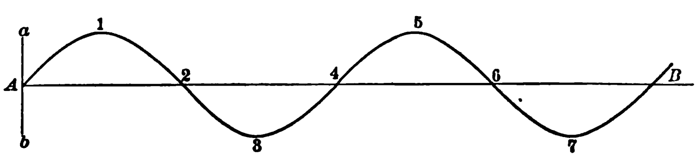

FIG. 86.

The distance from crest to crest (1 to 5), or from trough to trough (3 to 7), or from any point to the next point at which the vibrating particle was in the same stage of vibration or in the same phase (*A* to 4, or 2 to 6, or 4 to *B*), is called a *wave-length*. Evidently, the disturbance, i.e., the wave, advances just one wave-length in the time required for one vibration; this time is called the *vibration-period*.

Longitudinal Waves.

Experiment 67.—Make a spiral spring about 12 feet long by closely winding No. 18 spring-brass wire on a rod about half an inch in diameter. Fasten one end of the spiral to a hook on the wall, or clamp it in a vise, and tie short pieces of bright-colored strings into several of the coils. Holding the other end of the spiral in the hand, insert a finger-nail or knife-blade between two turns of the wire near the hand, and pull one of them further from the other. Suddenly release the coil, and a pulse will run along the spiral. Each coil swings to and fro, the coils being crowded closely together at one place, and more widely separated at another.

FIG. 87.

Experiment 68.—Tightly tie a sheet of writing paper over the large end of the tube used in Experiment 58, and hold a candle flame in front of the small end. Tap the paper diaphragm, and notice the consequent flickering of the flame.

130. Waves of Condensation and Rarefaction.—The advancing paper diaphragm or other vibrating body crowds the layers of air immediately in its front, thus setting up a condensation or push along the length of the tube, as explained in § 125. When the paper swings with

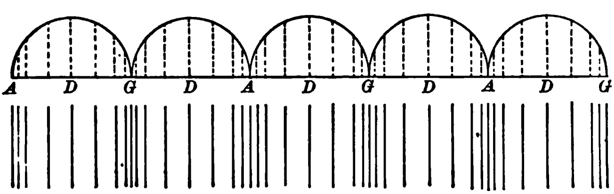

FIG. 88.

its pendulum-like motion in the opposite direction, the nearest layers of air follow it, thus setting up a rarefaction. As the paper diaphragm continues to vibrate, a series of condensations and rarefactions is sent along the tube, as shown in Fig. 88, which compare with Fig. 84.

The air particles are crowded unusually at *A* and *G*, where their velocity is the least, and are separated more widely at *D*, where their velocity is greatest. Just as a water wave consists of two parts, a crest and a trough, so *a sound wave consists of two parts, a condensation and a rarefaction.* The particles in a sound wave move with simple harmonic motion forward and backward in the line of propagation, and not across it. The vibrations are longitudinal, not transverse.

(*a*) A series of complete sound waves, such as would be set up in the open air, consists of alternate condensations and rarefactions advancing in the form of concentric spherical shells, at the common center of which is the sounding body. Any radius of the sphere is a line of propagation of the sound.

(*b*) The distance from any point to the next point that is in the same phase, as from condensation to condensation or from rarefaction to rarefaction, is a wave-length. The wave advances one wave-length in the time required for one vibration, or in a wave-period.

(*c*) A sinusoidal curve like that shown in Fig. 86 is commonly used to represent a sound wave. The parts above the horizontal line represent condensations, while the parts below that line represent rarefactions. The curve is merely a symbol for the sound wave, not a picture of one.

EXERCISES.

1. State clearly the difference between a transverse and a longitudinal wave. Illustrate.

2. The velocity of sound being given as 1,145 feet per second, what is the wave-length of a tone due to 458 vibrations per second?

3. It is a common experiment for one of two boys in swimming to hold his head under water while another at a distance strikes two stones together under water. The loudness of the sound heard by the first boy is painful and sometimes injurious, even when the distance is so great that the sound would be scarcely heard in the air. Explain.

4. If a blow is struck with a hammer upon one end of a long iron pipe, a listener at the other end may hear two sounds instead of one.

5. What is the difference between an oscillation and a vibration?

6. What is the difference between a motion of translation and one of vibration? Illustrate.

7. Cut a slit 1 mm. × 2 cm. in a postal card. Place a ruler below Fig. 86, and parallel with the printed lines. Place the edge of the card against the edge of the ruler, so that the slit shall be at right angles to the line, *AB*, at its end; i.e., so that *ab* may be seen through the slit. Slide the card with steady motion toward the right and along the edge of the ruler, observing the apparent motion of the short black line up and down the slit. How does that apparent motion compare with the simple harmonic motion of the pendulum?

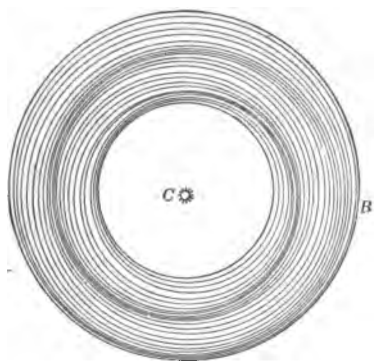

FIG. 89.

8. Mount a Crova disk about 30 cm. in diameter upon the spindle of a whirling-table. The disk may be bought for fifty cents or less. Hold a card with a narrow slit about 10 cm. long close to the disk, and so that the slit is parallel to the radius of the disk. Rotate the disk and watch the slit. The apparent motion of the dots along the slit indicate the way in which air particles actually move in a sound wave.

II. VELOCITY, REFLECTION, AND REFRACTION OF SOUND.

131. The Velocity of Sound depends upon two considerations, — the elasticity and the density of the medium. *It varies directly as the square root of the elasticity, and inversely as the square root of the density.*

(*a*) The velocity of the wave motion may be found by multiplying the wave-length by the number of vibrations per second, or the wave-length may be found by dividing the velocity by the number of vibrations.

(*b*) Careful experiment has established the fact that *the velocity of sound in air at the freezing temperature* (0° C. or 32° F.) *is about* 332 *m*., *or* 1,090 *feet per second.* Oxygen is sixteen times as dense as hydrogen. Under the same pressure, the elasticity is the same; hence, sound travels four times as fast in hydrogen as it does in oxygen. A change of pressure on a gas will change elasticity and density equally, and, therefore, will not affect the velocity of sound transmitted by the gas. If a confined portion of any gas is heated, its elasticity is increased without any change of density. Hence, a rise of temperature without barometric change increases the velocity of sound in the air. The added velocity is about 0.6 m., or 2 feet for each degree that the centigrade thermometer rises; or 0.33 m. or 1.12 feet for each degree that the Fahrenheit thermometer rises.

(*c*) Owing to the high elasticity of liquids and solids as compared with their densities, they transmit sound with great velocities. In water at 8° C., sound travels at the rate of 4,708 feet per second; in glass, the velocity is 14,850 feet, and in iron it is 16,820 feet; in lead, a metal of high density and low elasticity, the velocity of sound is 4,030 feet per second.

Reflection.

Experiment 69. — Repeat Experiment 66, and notice that the waves successively started by the hand are turned back at the other end of the rope and meet the advancing waves.

Experiment 70. — Slip the loops at the ends of the wire spiral used in Experiment 67 over hooks screwed into the sides of two boxes. Separate the boxes so as to support and slightly stretch the spiral, fastening the boxes by nailing them down or by loading them with sand. Start a pulse in the spiral, and notice that the wave runs to the other end, is turned back or reproduced in the same medium, moves along the spiral to its starting point, and so continues its journeys to and fro until its energy is dissipated. It looks as though a wave motion might be reflected as well as a motion of translation.

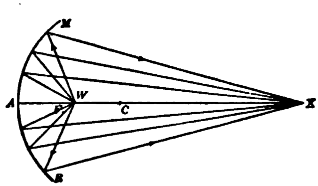

FIG. 90.

Experiment 71. — Hold a lamp reflector or other large concave mirror directly facing the sun, so as to bring the rays of light to a

focus. Move a piece of paper until you find the place where a spot on the paper is most brilliantly illuminated by the reflected rays, and measure the distance of this focus, *F*, from *A*, the center of the reflector (see Fig. 90). At some point, *W*, between *F* and *C*, the center of curvature of the reflector, hang a loud-ticking watch, and hunt for the point, *X*, at which the ear can most distinctly hear the ticking. Use a glass funnel as an ear-trumpet. Keep watch and ear in these positions, and have the reflector removed. The ticking will become less distinct or wholly inaudible.

132. Reflection of Sound. — When a sound wave strikes an obstacle, it is reflected in obedience to the principle given in § 47.

(*a*) Sound waves starting from a point, as *F*, may be twice reflected, as shown in Fig. 91, and thus made to converge at another point, as *F′*. By such means, the ticking of a watch may be made audible at a distance of two or three hundred feet. *Two reflectors so placed are said to be conjugate to each other.* This principle underlies the phenomena of some whispering galleries.

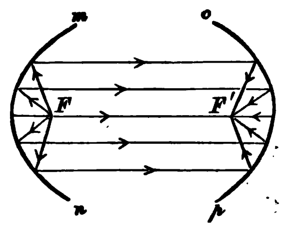

FIG. 91.

133. An Echo is a sound repeated by reflection so as to be heard again at its source.

(*a*) The time interval between a sound and its echo is the time required for a sound to travel twice the space interval between the source of the sound and the reflecting body. Remembering that at the ordinary temperature sound travels about 1,120 feet a second, and supposing a person to pronounce five syllables in a second, it will be seen that the echoing surface should be about 112 feet distant. If it is nearer than this, the reflected sound will return before the articulation is complete and confusedly blend with it.

Refraction.

Experiment 72. — Fill with carbon dioxide a large rubber toy balloon or other double-convex lens having easily flexible walls. Suspend a watch, and place yourself so that you can just hear its ticking.

Have the gas-filled lens moved back and forth in the line between watch and ear until the ticking is much more plainly heard. Use a glass-funnel as an ear-trumpet.

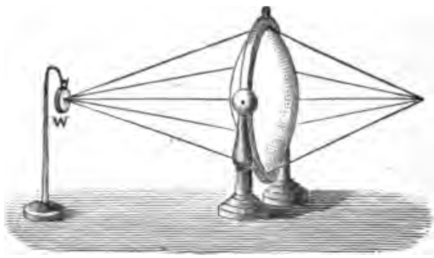

FIG. 92.

134. Refraction of Sound.—The lines of propagation of sound are ordinarily divergent. When sound waves pass obliquely from one medium to another of different density, the line of propagation is bent, as will be more fully explained in the chapter on radiant energy. *This bending of the lines of propagation is called refraction.*

EXERCISES.

1. If 18 seconds intervene between the flash and report of a gun, what is its distance, the temperature being 0° C.?

2. Steam was seen to escape from the whistle of a locomotive, and the sound was heard 7 seconds later. The temperature being 15° C., how far was the locomotive from the observer?

3. What is the length of sound waves propagated through air at a temperature of 15° C. by a tuning-fork that vibrates 224 times per second?

4. Determine the temperature of the air when the velocity of sound is 1,150 feet per second.

5. Why will an open hand or a palm-leaf fan held back of the ear often aid a partly deaf person in hearing a speaker?

6. A shot is fired before a cliff and the echo heard 6 seconds later. The temperature being 15° C., determine the distance of the cliff.

7. Taking the velocity of sound as 332 m., determine the length of the waves produced by a body vibrating 830 times per second.

8. When the velocity of sound is 1,128 feet, determine the rate of vibration of the vocal cords of a man whose voice sets up waves 12 feet long.

9. Why does sound travel more rapidly through the iron of a pipe than it does through the air contained in the pipe?

10. From the cyclopedia, cull the story of the prison built by Dionysius, the Syracusan tyrant, and explain its remarkable acoustic properties.

11. On opposite sides of the center of a disk of cardboard about 15 inches in diameter, cut out two sectors, as shown in Fig. 93. Mount the disk on a whirling-table. Sit beside the apparatus, so as to turn the driving wheel with one hand, and with the other hold a toy trumpet so that its axis shall be inclined to the surface of the disk, about midway between center and circumference. Rotate the disk steadily and sound the trumpet at the same time. Let other pupils take positions in a distant part of the room, as indicated by the law of reflected motion, so that the sound waves from the trumpet reflected by the disk will reach their ears. When the sectors pass before the mouth of the trumpet, the sound will become softer, and when the cardboard reflector passes, the sound will become stronger. Record a description and explanation of the exercise.

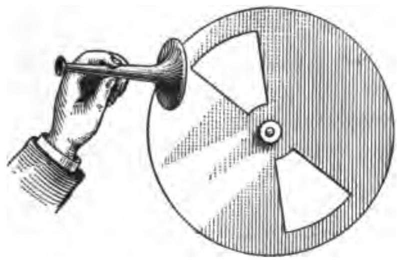

FIG. 93.

III. CHARACTERISTICS OF TONES.

135. Differences in Tones. — Sound waves differ in respect to amplitude, length, and form. *Variations in amplitude correspond to differences in intensity or loudness; differences in wave-length correspond to differences in pitch; differences in wave-form correspond to differences in timbre or musical quality.*

Intensity and Amplitude.

Experiment 73. — Set a tuning-fork in feeble vibration by striking it gently; the sound that you hear will be faint. Strike the fork a harder blow; its prongs will vibrate with greater energy and ampli-

tude, and the sound will be louder. For a similar experiment, pluck the string of a guitar.

136. Intensity and Amplitude.—*The intensity of a sound depends primarily upon the energy of vibration of the sonorous body*, and thence on the amplitude of the vibrating particles of the sound medium. The greater the amplitude, the greater the energy and the louder the sound.

Intensity and Distance.

Experiment 74.—Whisper into one end of a length (50 feet) of garden hose. A person listening with his ear at the other end of the hose can distinctly hear what is said although the sound is inaudible to a person holding the middle of the hose.

137. Intensity and Distance.—In the open air, a sound wave expands as a spherical shell, distributing its energy over a gradually increasing area, and correspondingly lessening the energy per unit of area. Hence, the intensity of sound varies inversely as the square of the distance from the sonorous body. This law is true only when the distance is so great that the sounding body may be considered a center from which the sound waves proceed.

(*a*) If the sound wave is not allowed to expand as a spherical shell, its energy cannot be thus diffused and its intensity will be conserved. Hence, the efficiency of speaking-tubes and speaking-trumpets.

Intensity and Area.

Experiment 75.—Strike a tuning-fork held in the hand. Notice the feeble sound. Strike the fork again and place the end of the handle upon a table. The loudness of the sound heard is remarkably increased.

Experiment 76.—Strike the fork and hold it near the ear, counting the number of seconds that you can hear it. Strike the fork again with equal force; place the end of the handle on the table and count the number of seconds that you can hear it.

138. Intensity and Area.—*When the sonorous body has a large surface, its vibrations set up well-marked condensations and rarefactions, and the consequent sound is correspondingly intense.*

(*a*) In the piano, violin, guitar, etc., the sound is due more to the vibrations of the bodies that carry the strings than to the vibrations of the strings themselves. The strings are too thin to impart enough motion to the air to be sensible at any considerable distance; but as they vibrate, their tremors are carried by the bridges to the sounding apparatus with which they are connected. These larger surfaces throw larger masses of air into vibration and thus greatly intensify the sound. It necessarily follows that the energy of the vibrating body is sooner exhausted.

Pitch.

Experiment 77.—Draw a finger-nail across the tips of the teeth of a comb, slowly the first time and rapidly the second time. Notice the difference in the pitch of the sounds produced.

FIG. 94.

Experiment 78.—From a piece of stiff cardboard, cut a disk $8\frac{1}{2}$ inches in diameter. From the same center, draw four circles with radii of $2\frac{1}{4}$ inches, $2\frac{3}{4}$ inches, $3\frac{1}{4}$ inches, and $3\frac{3}{4}$ inches, respectively. Divide the inner of these circumferences into 24 equal parts, the second into 30, the third into 36, and the fourth into 48. At each division, punch a $\frac{3}{16}$-inch (5 mm.) hole. Cut a hole at the center and mount the perforated disk on the spindle of a whirling-table, and *you have a simple form of the siren.* Rotate the disk slowly, blowing meanwhile through a tube of about $\frac{3}{16}$-inch bore, the nozzle of the

tube being held opposite the interior ring of holes. As each successive hole comes before the end of the tube, a puff of air goes through the disk. As the speed of the disk increases, the puffs become more frequent, and finally blend into a whizzing sound in which the ear can detect a smooth tone. As the disk is given an increasing velocity, this tone rises in pitch. With a given rate of rotation of the apparatus, the pitch will rise as the tube is moved outward in succession from the inner to the outer circle of perforations.

139. Pitch *is the characteristic of a sound or tone by which it is recognized as high or low. It depends upon the rapidity of the vibrations by which the sound is produced;* the more rapid the vibrations, the higher the pitch.

(*a*) One of the easiest ways of determining the number of vibrations that correspond to a given tone is to run the siren-disk at the speed that gives a tone of like pitch; the product of the number of revolutions of the disk per second, and the number of holes in the circle used is the vibration-number sought. Dividing the velocity of sound by the vibration-number gives the wave-length. The less the wave-length, the higher the pitch.

(*b*) Some persons are unable to hear low sounds that are distinctly audible to most persons; some are unable to recognize sounds of high pitch that are easily heard by others. The lower limit for most persons is probably represented by about 30 vibrations per second; the upper limit by about 40,000. A tone produced by more than 4,000 vibrations per second has little musical value.

(*c*) The approach of a sounding body to a listening ear is equivalent to increasing the vibration-number; the opposite is true when the sounding body recedes from the ear.

140. An Interval *is the difference or distance in pitch between two tones and is described by the ratio between the vibration-numbers of the two tones.* Thus, the interval of an *octave* is represented by the ratio 2 : 1; a *fifth*, 3 : 2; a *fourth*, 4 : 3; a *major third*, 5 : 4; and a *minor third*, 6 : 5.

141. A Musical Scale is a definite, standard series of tones for artistic purposes, and lying within a limiting interval. In modern music, this limiting interval is the octave.

142. The Diatonic Scale. — Starting from any tone, arbitrarily chosen and called the keynote, the interval of an octave may be traversed by seven definite steps, thus giving a series of eight tones that are very pleasing to the ear. The eighth tone of this group becomes the first tone (i.e., the keynote) of the group or octave above. *This familiar series of eight tones is called the gamut, or the major diatonic scale.* The series may be repeated in either direction to the limits of audible pitch. The names and relative vibration-numbers of these tones, and the intervals between them, are as follows: —

Relative names	1	2	3	4	5	6	7	8
Absolute names	C_3	D_3	E_3	F_3	G_3	A_3	B_3	C_4
Syllables	*do*	*re*	*mi*	*fa*	*sol*	*la*	*si*	*do*
Relative vibration-numbers . .	24	27	30	32	36	40	45	48
Vibration-ratios	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Intervals		$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

(*a*) The initial tone or keynote of such a series may have any number of vibrations, and whatever pitch is assigned to *C*, the number of vibrations of any tone may be found by multiplying the vibration-number for *C* by the vibration-ratios given above. Physicists assign to C_3, sometimes called *middle C*, 256 vibrations per second ($256 = 2^8$). Musicians and makers of musical instruments in this country and Europe have adopted the "international pitch," which gives for standard A_3, 435 vibrations per second. This corresponds to 258.6 vibrations for C_3.

(*b*) The octave is the interval most readily produced by the human voice, and seems to have a foundation in nature. When three tones with vibration-numbers as 4 : 5 : 6 are sounded together (e.g., *C*, *E*, *G*), a new quality seems to be added, and the combination produces a very pleasing sensation. The tones are in harmony, or in accord with each other. *Such simultaneous sounding of three or more con-*

cordant tones constitutes a chord, of which there are several kinds. The three tones above mentioned (i.e., C, E, G) constitute a ***major chord***.

143. Chromatic Scale. — Twenty-four different scales are ordinarily used in music. They require no fewer than seventy-two tones within the limit of an octave. To use so many tones in each octave of keyed instruments, such as the piano and organ, is a practical impossibility. As many of these tones differ from each other but little, musicians have agreed to make a compromise, and to divide the octave into twelve equal intervals, called semi-tones. ***The series of thirteen semi-tones separated by the twelve equal intervals, constitutes the modern chromatic scale.***

(*a*) The eight tones nearest those already described are named as we have already designated them, while the five interpolated tones, corresponding to the black keys on the piano keyboard, are called *sharps* of the tones immediately below them, or *flats* of the tones next above them. The compromising process between theory and practice, or the principle by which the octave is divided into twelve equal intervals, is called *equal temperament*. In this system, the only perfect interval is the octave, and all chords are slightly "out of tune." The interval in this scale is $\sqrt[12]{2} = 1.05946$.

Tones and Overtones.

Experiment 79. — Bow or pluck the string of a sonometer near its end, thus setting it in vibration as a whole. The string will have the

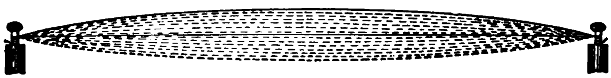

FIG. 95.

appearance of a single spindle as shown in Fig. 95, and will sound the lowest tone that it is capable of producing. Lightly touch the wire at its middle point with the tip of the finger or the beard of a quill; the wire will vibrate in halves (Fig. 96) and ***sound a tone an octave above that previously heard***. You may even hear both tones at

the same time. The point of apparent rest between the vibrating segments is called a *node.* Again cause the string to vibrate and touch it at one-third its length. The vibrating string divides into thirds,

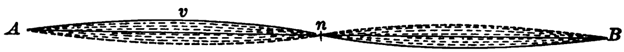

FIG. 96.

as shown in Fig. 97, and emits a tone that the trained ear recognizes as the fifth of the octave above that first sounded. Probably both sounds will be heard at the same time. The string should be touched at *n* and bowed at *v*, as shown in Figs. 96 and 97.

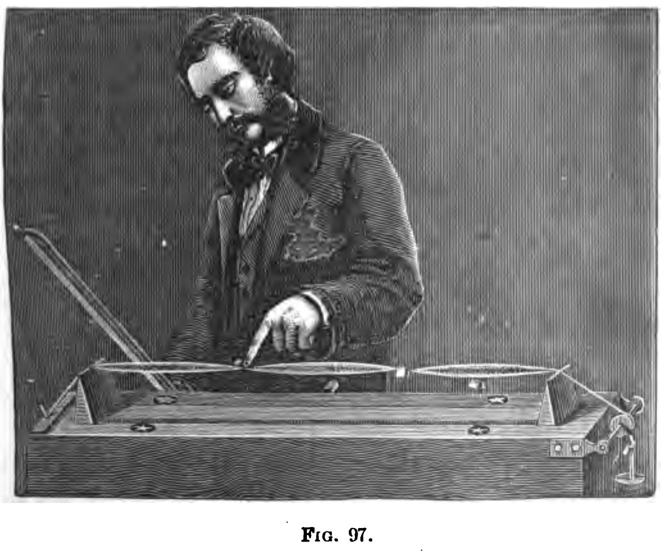

FIG. 97.

144. Fundamental Tones and Overtones. — *The tone that is sounded by a body vibrating as a whole, i.e., the lowest tone that such a body can produce, is called its fundamental or primary tone. The tones produced by the vibrating segments of sonorous bodies are called overtones, partial tones, or harmonics.* The partial tones are named first, second,

third, etc., in the order of their vibration-numbers, beginning with the fundamental. The interval from the fundamental to the first overtone is an octave; to the second, an octave and a fifth; to the third, two octaves, etc.

(a) It is customary to regard both ends of the string as nodes. The points of greatest vibration, midway between the nodes, are called *anti-nodes*. If little Λ-shaped riders, made of slips of paper bent in the middle, are placed on a string, and the string is then made to vibrate in segments, the riders at the nodes will remain in position while those at the anti-nodes will be thrown off as shown in Fig. 97.

145. Quality or Timbre is the characteristic by which we distinguish one tone from another of the same intensity and pitch. The middle *C* of a piano is different from the same tone of an organ, and any tone of a flute is distinguishable from any tone of a violin. *The physical basis of quality is wave-form*, and is due to the number, relative intensities, and relative phases of the overtones that accompany the fundamental.

(a) The well-trained ear can detect several tones when a piano-key is struck. In other words, the sound of a vibrating piano-wire is compound. The sound of a tuning-fork is a fairly good example of a simple sound.

(b) Figure 98 represents the compounding of a fundamental with its second overtone. The fundamental is represented by the dotted line while the resultant compound tone is represented by the continuous line *ADD'B*. Such combinations may be made in almost endless variety, each combination representing a compound tone that varies from all of the others.

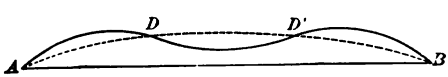

FIG. 98.

146. The Graphic Method of studying sounds is largely used and may be briefly explained: Suppose a sheet of smoked paper fastened upon the surface of a cylinder that

is so mounted that, when it is turned by a crank, the screw cut upon the axis moves the cylinder endwise, as shown in Fig. 99. Such an instrument is called a *vibroscope.*

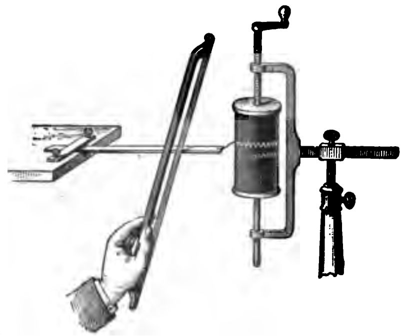

FIG. 99.

(*a*) When a style attached to a vibrating tuning-fork just touches the paper, and the crank is turned, the vibrations will be traced in the form of a sinusoidal spiral upon the smoked surface, the amplitude, length, and form of each wave being truthfully recorded. By counting the number of waves traced in one second, we obtain directly the vibration-number of the fork. The wave-forms that correspond even to a very complex tone may thus be secured for study or illustration. Such a record may be

FIG. 100.

written parallel with that of a tuning-fork of known frequency (i.e., vibration-number), as in Fig. 100, and comparative study thus facilitated.

147. The Optical Method of studying sounds, like the graphic, has the advantage of being independent of the sense of hearing. When a steady flame is viewed by its reflection in a rotating mirror, it appears as a luminous ribbon of uniform width. If the flame is pulsating, the edge of the ribbon will become indentated in a very remarkable manner. A series of sonorous waves may be conducted by a tube to one side of the dividing membrane of a "manometric capsule," *B*, the other side of which is connected with a gas supply and a gas jet. The waves

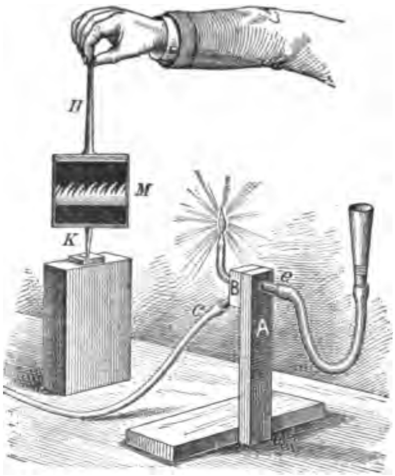

FIG. 101.

set up vibrations in the membrane and pulsations in the flame. When the pulsating flame is observed by its reflection in the rotating mirror, *M*, there is an appearance known as a manometric flame. Each projection of this image corresponds to the condensation of a sound wave, and each depression to the rarefaction.

(*a*) Figure 102 represents the flame produced by the simple tone of a tuning-fork. Figure 103 corresponds to the tone of a fork that is an octave higher, twice as many tongues being crowded into the same space. Figure 104 represents the appearance caused by blending the tones of the two forks. The alternate condensations sent out by the fork of higher pitch unite with the condensations sent out by the fork of lower pitch, thus making the flame jump higher by their combined action on the diaphragm.

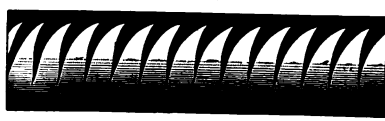

FIG. 102.

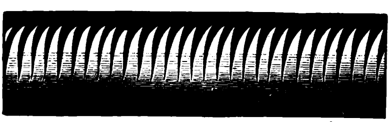

FIG. 103.

EXERCISES.

1. If a musical sound is due to 144 vibrations, to how many vibrations will its - - - fth, and octave, re- be due?

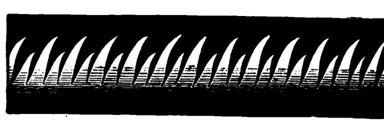

FIG. 104.

2. If a tone is produced by 264 vibrations per second, what number will represent the vibrations of the tone a fifth above its octave?

Ans. 792.

3. A given tone is found to be in unison with the tone emitted by the inner row of holes of the siren described in Experiment 78 when the disk is turned at the uniform rate of 640 times in 30 seconds. Assigning 256 vibrations for middle *C*, name the given tone.

4. Is there any difference in the pitch of a locomotive-whistle when the locomotive is standing still, when it is rapidly approaching the observer, and when it is rapidly moving from him? If so, describe and explain it.

5. If an observer should approach a sounding organ-pipe with the velocity of sound, what would be the effect upon the pitch of the tone?

6. If an observer should recede from the source of a musical tone with a velocity a little less than that of sound, what would be the effect upon the pitch of the tone?

7. Suppose that when an orchestra has nearly finished a performance, an observer should move away from the orchestra with a velocity twice that of sound. Describe his relation to the sounds previously executed by the orchestra.

8. Bow a sonometer-string vigorously, and while it is sounding lessen the tension. Explain the discordant groan-like sound that is produced.

9. Make another disk for the siren used in Experiment 78, making eight circles of holes, each circle having, in order, the number of holes indicated by the relative vibration-numbers given in § 142. Put this disk upon the whirling-table and rotate it at such a uniform speed that the puffs made by the inner circle of twenty-four holes shall give a smooth musical tone. Move the nozzle of the tube through which you blow over the several circles in succession and name the familiar series of tones that you hear.

IV. CO-VIBRATION.

Coincident Waves.

Experiment 80. — Vary Experiment 69 by timing the movements of the hand so that an advancing crest shall meet a returning trough near the middle of the rope. The rope particles at this point, being thus simultaneously acted upon by opposite forces, will remain at rest

or nearly so. The resultant will be the difference of the components. *Thus, one wave may be made to destroy another wave.*

148. Coincident Waves. — Just as, when one crest coincides with another, the wave has an increased height, and when a crest coincides with an equal trough, the wave disappears, so, when a condensation coincides with another condensation, the actual motions of the particles of the sound medium are increased, and, when a condensation coincides with a rarefaction, said motions are reduced or destroyed. Such increased resultant motions of the material particles imply an increased loudness of the sound. Such diminished resultant motions imply an enfeebled sound or perhaps silence.

Sympathetic Vibrations.

Experiment 81. — Repeat Experiment 4, and vary it by setting the heavy pendulum in motion by the cumulative action of well-timed puffs of air from the mouth or from a hand-bellows.

Experiment 82. — Suspend several pendulums from a frame as shown in Fig. 33. Make two of equal length, so that they will vibrate at the same rate. Be sure that they will thus vibrate. The other pendulums are to be of different lengths. Set *a* in vibration. The swinging of *a* will produce slight vibrations in the frame, which will, in turn, transmit them to the other pendulums. As the successive impulses thus imparted by *a* keep time with the vibrations of *b*, this energy accumulates in *b*, which is soon set in perceptible vibration. As these impulses do not keep time with the vibrations of the other pendulums, there can be no such marked accumulation of energy in them, for many of the impulses will act in opposition to the motions produced by previous impulses, and thus weaken if not destroy them.

Experiment 83. — Tune the two strings of a sonometer to perfect unison. Place two or three paper "riders" upon one of the strings, and gently bow the other. The "riders" will be dismounted from the first string, even if the vibrations of the second string are not audible. The vibrant energy was carried from one string through the bridges of the sonometer to the other string and there accumulated. Change the tension of one of the strings, thus destroying the

unison, and try to repeat the experiment. Notice that the sympathetic vibrations are not produced.

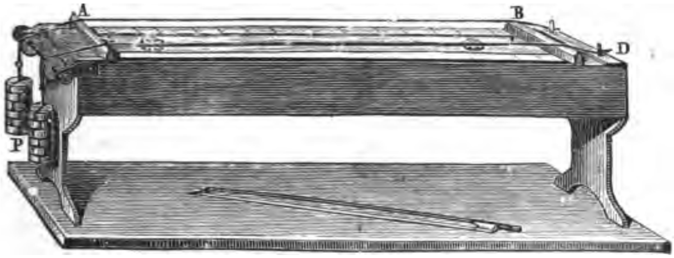

FIG. 105.

Experiment 84. — Place two mounted tuning-forks that are in perfect unison several feet apart, and with the openings of their resonant boxes facing each other. Sound one of the forks, and notice its pitch. After a second or two, touch the prongs to stop their motion. It will be found that the second fork is giving forth a sound of the same pitch as that originally produced by the first fork. The successive pulses were transmitted by the intervening air. With wax, fasten a small weight to one of the prongs of the second fork. An attempt to repeat the experiment will fail.

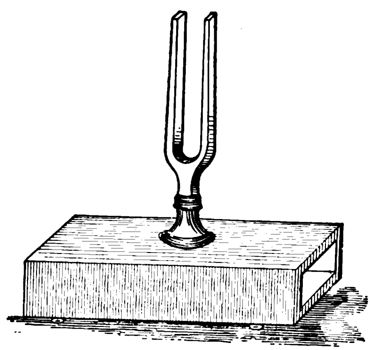

FIG. 106.

149. Sympathetic Vibrations. — The last few experiments show that sound may produce motion. The most important feature now to be noticed is that *the sonorous body accumulates only the particular kind of vibration that it is capable of producing.*

Resonance.

Experiment 85. — Hold a vibrating tuning-fork over the mouth of a cylindrical jar about 15 or 18 inches deep, and notice the feebleness

of the sound. Pour in water, as shown in Fig. 107, and notice that, when the liquid reaches a certain level, the sound suddenly becomes much louder. The water has shortened the air-column until it is able to vibrate in unison with the fork. If more water is added, the sound will become weaker. If a fork of different pitch is used, the length of the air-column must be changed, said length being about one-fourth the length of the wave produced by the fork.

FIG. 107.

150. Resonance.—*The increase of sound by the sympathetic vibrations of a body other than that by which it was originally produced is called resonance.* The apparatus used to produce such an effect is called a *resonator.*

(*a*) Resonance occurs in connection with all sound, and is carefully utilized in musical instruments. Sounding-boards like that of the piano, and diaphragms like those of the phonograph and telephone, are sensitive to any vibratory motion within the limits of ordinary audition.

(*b*) Helmholtz constructed a series of resonators, each one of which responds powerfully to a single tone of certain pitch or wave-length. They are metallic vessels, nearly spherical, having an opening, as at *A* in Fig. 108, for the admission of the sound waves. The funnel-shaped projection at *B* has a small opening, and is inserted in the outer ear of the observer. Such resonators are largely used in the analysis of complex tones.

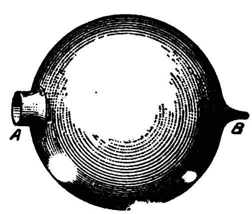

FIG. 108.

Interference.

Experiment 86. — Hold a vibrating tuning-fork near the ear, and slowly turn it between the fingers. During a single complete rotation, four positions of full sound and four positions of silence will be found. When a side of the fork is parallel to the ear, the sound is plainly audible; when a corner of a prong is turned toward the ear the waves from one prong destroy the waves started by the other.

Experiment 87. — Hold a vibrating tuning-fork at the mouth of a resonator, and slowly turn it upon its axis. Notice that, in certain positions of the fork, its tone is nearly inaudible. While the tube is in one of these positions, slip a paper tube over one of the prongs, as shown in Fig. 109, being careful not to touch it. The sound will be restored, because the interfering sound has been removed. When, by removing the paper tube, we restore the sound of the second prong, we demonstrate the almost paradoxical fact that *sound added to sound may produce silence.* See § 148.

FIG. 109.

151. Interference. — As the words are generally used, the *interference of sound signifies the union of two or more systems of sound waves in such a way as to weaken or destroy the sound.* It is the leading characteristic property of wave motion.

Beats.

Experiment 88. — Simultaneously sound two large tuning-forks that are in unison, and notice that the sound is as smooth as if only one

fork was sounding. Load one of the prongs of one of the forks with wax, sound both forks, and notice that the sound is not smooth, but that a series of palpitations or beats is easily perceptible.

Experiment 89. — In a quiet room, strike simultaneously one of the lower white keys of a piano, and the adjoining black key. A similar series of beats will be heard.

152. Beats. — *The peculiar pulsation arising from the successive reinforcement and interference of two tones differing slightly in pitch is called a beat.*

(*a*) If two tuning-forks, *A* and *B*, vibrating respectively 255 and 256 times a second, are set in vibration at the same time, the first result will be an intensity of sound greater than that of either. After half a second, *B* having gained half a vibration upon *A*, the waves will meet in opposite phases, and the sound will be weakened or destroyed. At the end of the second, we shall have another reinforcement; at the middle of the next second, another interference. The number of beats per second equals the difference of the two vibration-numbers.

153. Noise and Music. — A noise is a sound so complex that the ordinary powers of the ear fail to resolve it into its constituent tones. A simple tone is incapable of resolution, by reason of its simplicity. A combination of sounds that may be easily resolved into simple tones is a musical sound. The distinction is often difficult.

EXERCISES.

1. How can a deaf person determine whether a given tone is simple or compound?

2. If two tuning-forks, vibrating respectively 256 and 259 times per second, are simultaneously sounded near each other, what phenomena will follow?

3. A musical string, known to vibrate 400 times a second, gives a certain tone. A second string, sounded a moment later, seems to give the same tone. When sounded together, two beats per second are noticeable. Are the strings in unison? If not, what is the rate of vibration of the second string?

4. A tuning-fork produces a strong resonance when held over a jar 15 inches long. (*a*) Find the wave-length of the fork. (*b*) Find the wave-period. Assume a temperature of 15° C.

5. A tuning-fork held over a tall glass jar, into which water is slowly poured, receives its maximum reinforcement of sound when the resonant air-column is 64.8 cm. long. Assuming that the fork is accurately tuned to give an exact number of vibrations per second, noting the fact that the thermometer records a temperature of 16° C., and keeping in mind the probability of slight experimental error, determine the vibration-number of the fork. *Ans.* 132.

6. One of two tuning-forks, each tuned to 512 vibrations per second, is loaded with wax. The forks are simultaneously sounded, and 20 distinct beats are heard in 10 seconds. What is the vibration-number of the loaded fork?

7. Figure 110 represents two series of sound waves traveling together. The full line represents one series and the dotted line another. What

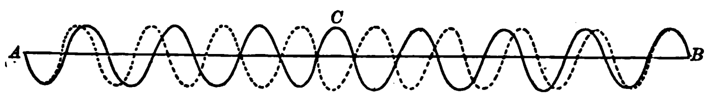

FIG. 110.

phenomenon would result from such a combination of tones as is here represented? Describe the condition of affairs as represented at *A*, *B*, and *C* respectively.

8. Stretch a string horizontally between two fixed supports. From this string suspend two bullet pendulums by threads about a meter long. Swing one of these pendulums across the direction of the horizontal string. Describe and explain the result that you think the exercise was intended to bring to your notice.

9. Remove the cover from a piano, depress the pedal so as to lift the dampers from all the wires, hold the lips near the wires, and sing the vowel, *a*, with the sound it has in "fate," and prolong the tone. Listen for the sympathetic response of the piano. Repeat the experiment, singing the same vowel with the sound it has in "father," and then the vowel, *o*, with the sound it has in "tone."

10. Get a glass tube about $\frac{3}{4}$ of an inch in diameter and 12 inches long. Into this tube thrust a neatly fitting cork. Move the cork with a ramrod until, by trial, you have adjusted the tube for maximum

resonance with a tuning-fork, e.g., one marked "Philharmonic A." Support the tube with its mouth close to the disk of the siren shown in Fig. 94, and facing one of the circles of holes. Hold the nozzle of the tube on the other side of the disk and just opposite the mouth of the resonant tube. Turn the disk with gradually increasing speed, and blow air through the tube. When the sound is at its maximum, the siren-tone will be in unison with the tone of the fork by which the resonant tube was tuned. Determine the vibration-number of the fork.

FIG. 111.

11. Support a wooden rod about an inch square and three feet long with its lower end resting upon the cover of a music-box that is sounding. Wrap the music-box in cotton-wool and manifold layers of woolen cloth, until no sound from the box can be heard. Carefully balance a guitar or violin upon the top end of the rod. Describe and explain the consequent phenomenon.

V. THE LAWS OF VIBRATION.

154. Vibrations of Strings. — The transverse vibrations of strings are the most important of the vibrations that give rise to musical tones, and may be conveniently studied with the aid of a sonometer. (See Fig. 105.)

(*a*) When used for the production of musical tones, strings are fastened at their ends, stretched to proper tension, and then made to vibrate by bowing, as in the violin; by plucking, as in the guitar or banjo; or by striking them with a light hammer, as in the piano or dulcimer. The manner of producing the vibrations has little effect upon the tone, which is chiefly determined by the length, diameter, density, and tension of the string itself.

Laws of Vibrations of Strings.

Experiment 90. — Remove the sliding bridge of the sonometer, stretch one of the strings and pluck or bow it near its end. Notice the pitch of the tone. Place the sliding bridge at the middle of the

scale on the sonometer box so as to halve the length of the string; then bow as before. Notice that the pitch of the tone is an octave higher.

Experiment 91. — Stretch, with unequal and known tension, two wires of the same diameter and material, and, with the movable bridge, shorten the wire that carries the smaller weight until it sounds in unison with the other. Notice that the lengths of the strings vary as the square roots of the weights or tensions. The length of the string is the distance between the edges of the supporting bridges.

NOTE. — By similarly using two iron wires of different diameters, and under equal tension, a third fact may be developed; a like experiment with a brass and a steel wire of the same diameter may develop a fourth fact.

155. Laws of Vibrations of Strings. — Countless experiments have established the following facts relative to musical strings: —

(1) *Other conditions being alike, the vibration-numbers vary inversely as the lengths.*

(2) *Other conditions being alike, the vibration-numbers vary directly as the square roots of the tensions.*

(3) *Other conditions being alike, the vibration-numbers vary inversely as the diameters.*

(4) *Other conditions being alike, the vibration-numbers vary inversely as the square roots of the densities.*

(*a*) The third and fourth laws may be consolidated as follows: — *Other conditions being alike, the vibration-numbers vary inversely as the square roots of the weights per linear unit.*

Air-Columns.

Experiment 92. — Make a reed-pipe by cutting a piece of wheat straw eight inches (20 cm.) long so as to have a knot at one end. At *r*, about an inch from the knot, cut inward about a quarter of the straw's diameter; turn the knife-blade flat and draw it toward the knot. The strip, *rr'*, thus raised is a reed; the straw itself is a reed-pipe. When the reed is placed in the mouth, the lips firmly closed

around the straw between *r* and *s* and the breath driven through the apparatus, the reed vibrates and produces vibrations in the air-column of the pipe. Notice the pitch of the tone thus produced. Cut off

FIG. 112.

two inches from the end of the pipe at *s*. Blow through the pipe as before and notice that the pitch is raised. Cut off two inches more, sound the pipe, and notice that the pitch is still higher.

156. Vibrations of Air-Columns. — Experiments 85 and 91 show that when gases are confined in tubes they may be made to vibrate as sonorous bodies. The air-column may be set in vibration by a vibrating tongue, as in the reed-pipe of Experiment 91, or in reed instruments like the melodeon, accordion, clarinet, etc., or by the fluttering of air particles driven against the edge of an opening in a tube, as in the whistle, fife, flute, or organ-pipe.

(*a*) Whatever the way of producing the vibrations, the dimensions of the air-column itself determine the tone. In Experiment 91, we saw that the air-column, and not the straw tongue, determined the pitch.

Laws of Vibrations of Air-Columns.

Experiment 93. — Fit a cork loosely as a piston into the end of a glass tube about 2 cm. in diameter and 30 cm. long. Blow across the open end of the tube so as to produce a steady tone. It may be more easy to do this if you use a mouthpiece made by flattening the end of a piece of brass tubing. Notice the pitch of the tone produced, and measure the length of the air-column in the tube. By trial, determine the lengths of the air-columns that will give the tones of the gamut, and compare the relative lengths with the relative vibration-numbers given in § 142.

Experiment 94. — Provide two glass tubes of the same diameter (about 2.5 cm.), one being half as long as the other (e.g., 10 cm. and 20 cm.). Blow across the end of the longer tube so as to produce its lowest tone while the other end of the tube is open. Notice the pitch.

Stop one end of the shorter tube with the hand, and blow across the open end so as to produce the lowest tone. Notice that the pitch of the short stopped-pipe is the same as that of the long open-pipe. Of course, if the school is provided with an assortment of organ-pipes, or of Quincke's acoustic tubes (as is desirable), it is better to use them.

157. Laws of Vibrations of Air-Columns. — (1) *The vibration-numbers of air-columns vary inversely as their lengths.* (2) *The pitch of a closed-pipe is an octave below that of an open-pipe of equal length.*

(*a*) The two ends of an open-pipe sounding its fundamental are the middle points of ventral segments; the middle of the pipe is a node. The length of the air-column is half the wave-length. In the stopped-pipe sounding its fundamental, the node is at the end, and the length of the air-column is a fourth of the wave-length.

(*b*) If a hole is made in the side of a pipe at a point occupied by a node, the point is at once changed to the middle of a ventral segment, and there is a corresponding change of pitch. This action is familiarly shown in the fife and flute.

158. The Vibrations of Rods may be transverse, longitudinal, or torsional. Transverse vibrations are familiarly illustrated in the music-box, jews'-harp, tuning-fork, etc. By clasping a vertical glass tube with one hand, and rubbing the upper half with a wetted cloth held in the other, it is possible to produce longitudinal vibrations that will shatter the lower part of the tube. If a violin-bow is drawn around a rod that is clamped at one end, the rod will twist and untwist with vibrations that are as isochronous as those of a tuning-fork, emitting a tone a little lower than that produced by longitudinal vibrations of the same rod having the same number of segmental divisions.

Vibrations of Plates.

Experiment 95. — Support, as shown in Fig. 113, a glass or brass plate, square or round, and strew it evenly with fine sand. Place the finger at any point on the edge of the plate (e.g., at the middle of

one side) so as to form a node there, and draw a violin-bow at a point properly chosen (e.g., near the adjacent corner). The sand immediately begins to dance on the plate and arrange itself along nodal lines. By changing the nodal points and bowing properly, other sand-figures may be produced, one of which is shown in Fig. 113.

FIG. 113.

159. Vibrations of Plates. — The arrangement of nodal lines in the Chladni figures just illustrated is determined by the relative positions of the point that is bowed and the point that is touched with the finger. The figures may be produced in great variety. As the complexity of the figures produced on a given plate increases, the pitch of the corresponding tone rises, *the same figure always answering to the same tone.*

Vibrations of Bells.

Experiment 96. — Draw a violin-bow across the edge of a large goblet nearly full of water on the surface of which cork dust or powdered sulphur has been evenly sifted. When this glass bell sounds its fundamental tone, it vibrates in four segments, and the surface of the water tells the story by a record like that shown in Fig. 114. A few vigorous strokes of the bow would set up vibrations of amplitude sufficient to break the bell.

FIG 114.

160. Vibrations of Bells. — Just as a tuning-fork may be looked upon as a rod bent into a U-shape, so a bell

may be considered as a disk bent into a cup shape. Like a disk, it sounds its fundamental tone when vibrating in four segments, and the number of segments is always even.

EXERCISES.

1. A musical string vibrates 200 times a second. State what takes place when the string is lengthened or shortened with no change of tension; and what change takes place when the tension is made more or less, the length remaining the same.

2. A certain string vibrates 100 times a second. (*a*) Find the vibration-number of a similar string, twice as long, stretched by the same weight. (*b*) Of one that is half as long.

3. A string sounding C_3 is 18 inches long. Must it be lengthened or shortened and how much to give the tone D_3?

4. A sonometer string is stretched by a load of 16 pounds. What load must be given to it so that it may sound a tone an octave lower?

5. A tube open at both ends is to produce a tone corresponding to 32 vibrations per second. Taking the velocity of sound as 1,120 feet, find the length of the tube. If the number of vibrations is 4,480, find the length of the tube.

6. Find the length of an organ-pipe the waves of which are four feet long, the pipe being open at both ends. Find the length, the pipe being closed at one end.

7. What will be the relative vibration-numbers of two strings of equal length, diameter, and tension, one being made of catgut and the other of brass, the density of brass being nine times that of catgut?

8. Bring the siren into unison with a tuning-fork. Turning the wheel regularly for 10 seconds at the rate that gives unison, determine the number of puffs per second, and thus determine the vibration-number of the fork.

CHAPTER IV.

HEAT: MOLECULAR PHYSICS.

I. NATURE OF HEAT, TEMPERATURE, ETC.

161. Heat *is a form of energy into which all other forms of energy are convertible. It consists in the agitation of the molecules of matter, and is generally recognized by the sensation of warmth to which it gives rise.*

162. The Temperature *of a body is its state considered with reference to its ability to communicate heat to other bodies.* When two bodies are brought together, there is a tendency toward an equalization of temperature. The one that gives the greater amount of heat has the higher temperature.

(*a*) Water flows from a point of high to one of low level. Electrification flows from a point of high to one of low potential. Heat flows from a point of high to one of low temperature.

(*b*) An addition of heat may increase the velocity of the molecular motion or it may do another kind of work. When a body receives heat, its temperature generally rises, but sometimes a change of condition results instead. When a body gives up heat, its temperature falls or its physical condition changes.

An Effect of Heat.

Experiment 97. — Connect, by a perforated cork, a piece of glass tubing about 50 cm. long to a Florence flask. Put water that has been colored with red ink into the apparatus so that it partly fills the upright tube. Mark the level of the water in the tube by a rubber band or in some other convenient way. Immerse the flask in hot water and carefully observe the level of the water in the tube.

163. Expansion. — Experiment 97 shows that one effect of heating a body is to increase its volume. This expansion is due to the increase of the molecular motions; the amount of the expansion is definitely related to the increase of temperature.

164. A Thermometer *is an instrument for measuring temperatures.* In its most common form, it consists of a liquid-filled bulb and a tube of uniform bore, as illustrated in Experiment 97. The liquid generally used is mercury or alcohol. The upper part of the tube is freed from air and sealed by fusion. A scale of equal parts is added for the measurement of the rise or fall of the liquid in the tube.

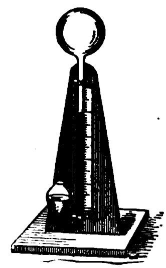

FIG. 115.

(*a*) An air thermometer consists essentially of a large glass bulb at the upper end of a tube of small but uniform bore, the lower end of which dips into colored water. Any slight change of temperature affects the elastic force of the air in the bulb and changes the height of the liquid column. It is a thermoscope rather than a thermometer; i.e., it enables us to detect slight changes of temperature rather than to measure temperatures.

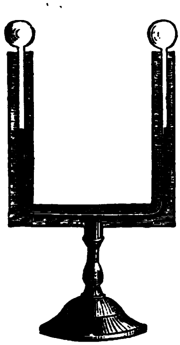

FIG. 116.

(*b*) The differential thermometer shows the difference in temperature of two neighboring places by the expansion of air in one of the two bulbs that are connected by a bent glass tube containing some liquid not easily volatile.

(*c*) Mercury freezes at about $-39°$ C. For temperatures lower than $-38°$ C., an alcohol thermometer is generally used. Mercury boils at about 350° C. Temperatures higher than 300° C. are generally measured by the expansion of a metal rod or by using an air thermometer with a porcelain or platinum bulb.

(*d*) In every thermometer there are two fixed points, called the freezing-point and the boiling-point. The first of these indicates the temperature of melting ice; the other, the tem-

perature of steam as it escapes from water boiling under the ordinary atmospheric pressure (76 cm. of mercury). The distance between these fixed points is divided into equal parts according to different scales. The two scales chiefly used in this country are the centigrade (or Celsius) and Fahrenheit's. For these scales, the fixed points, determined as just explained, are marked as follows: —

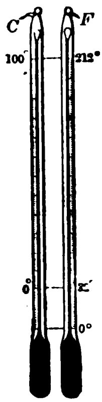

FIG. 117.

	Centigrade.	Fahrenheit.
Freezing-point,	0°	32°
Boiling-point,	100°	212°

The tube between these two points is divided into 100 equal parts for the centigrade scale, and into 180 for Fahrenheit's. Either scale may be extended beyond either fixed point as far as is desired. The divisions below zero are considered negative; e.g., – 10° signifies 10 degrees below zero. The scales are designated by their respective initial letters, as 5° C., or 41° F. Unless otherwise stated, the thermometer readings given in this book are in centigrade degrees.

Since 0° C. corresponds to 32° F., and an interval of 1 centigrade degree equals an interval of 1.8 Fahrenheit degrees, we may reduce centigrade readings to Fahrenheit readings by multiplying the number of centigrade degrees by 1.8 and adding 32. Similarly, we may reduce Fahrenheit degrees to centigrade degrees by subtracting 32 from the number of Fahrenheit degrees and dividing the remainder by 1.8.

165. Absolute Zero of Temperature. — *The temperature at which the molecular motions constituting heat wholly cease is called the absolute zero.* It has never been reached, but theoretical considerations indicate that it is 273° below the centigrade zero.

(*a*) Absolute temperatures are obtained by adding 273 to the readings of a centigrade thermometer, or 460 to the readings of a Fahrenheit thermometer.

EXERCISES.

1. The difference between the temperatures of two bodies is 36 Fahrenheit degrees. Express the difference in centigrade degrees.

2. The difference between the temperatures of two bodies is 35 centigrade degrees. Express the difference in Fahrenheit degrees.

3. (*a*) Express the temperature 68° F. in the centigrade scale. (*b*) Express the temperature 20° C. in the Fahrenheit scale.

4. What is the corresponding centigrade reading for 50° F.?

5. Suppose that one of the flat faces of a tin can was painted with a mixture of lampblack and oil, the opposite face of the can being left bright; that the can thus prepared was filled with hot water and hung between the bulbs of a differential thermometer with the painted side facing one of the bulbs; and that the liquid moved toward the bulb that was opposite the bright face of the can. What inference would you draw concerning the effect of the paint on the facility with which tin at a given temperature emits heat?

6. Suppose that when the Florence flask used in Experiment 97 was immersed in hot water, the level of the liquid in the tube fell a little before it began to rise. How would you explain such an effect?

7. Describe very briefly the molecular agitations of a body at a temperature of − 273°.

8. What is the absolute temperature of this room at this time?

II. THE PRODUCTION AND TRANSFERENCE OF HEAT, ETC.

166. Sources of Heat. — The sun is the great source of thermal energy, but man is able to transform other forms of energy into heat.

Transformations of Energy.

Experiment 98. — Rub a metal button on the floor or carpet. It soon becomes uncomfortably warm.

Experiment 99. — Place a nail or coin on an anvil or stone and hammer it vigorously. It soon becomes too hot to handle. In this way, blacksmiths sometimes heat iron rods to redness.

Experiment 100. — Cut a thin slice from a stick of phosphorus under water. Carry the slice on the knife-blade, and press it between the folds of a handkerchief to dry it. Moving it again upon the knife-blade, place it upon a brick. Carefully place a single crystal of iodine upon the phosphorus. Some of the potential energy of chemical separation will be transformed into the kinetic energy of heat.

167. Production of Heat. — The experiments just given illustrate some of the methods by which other forms of energy are transformed into heat. Such transformations are continually taking place, and the attention has only to be called to the subject that they may be recognized.

Diffusion of Heat.

Experiment 101. — Thrust an iron poker into the fire. The end of the poker that is held in the hand soon grows warm. The rod has been heated through its whole length, and there is a gradual rise of temperature from the end held in the hand to the end that is in the fire. Hold the hand over the stove, and it is warmed by the ascending current of heated air. Hold the hand in front of the stove and, in some way that we shall understand better by and by, it is warmed.

168. Diffusion of Heat. — Heat is transferred from one point to another in two ways, *conduction* and *convection.*

(*a*) It is often said that heat is transferred in a third way, viz., by *radiation*. What is sometimes called *radiant heat* will be considered in the next chapter.

Conductivity of Solids.

Experiment 102. — Instead of the iron poker used in Experiment 101, use a glass rod or a wooden stick. The end in the fire may be melted or burned without rendering the other end uncomfortably warm.

Experiment 103. — Put a silver and a German-silver spoon into the same vessel of hot water. The handle of the former will become hot much sooner than that of the latter.

Experiment 104. — Provide two stout wires, one of iron and one of copper, each 40 or 50 cm. long. Twist them together for about 10 cm., and spread the untwisted parts so as to form a fork with a twisted handle. Dip the prongs of the fork into melted paraffin wax, thus coating them. Balance the fork on a coverless crayon box, and place a lamp flame under the overhanging handle. Notice which prong melts its wax coat to the greater distance.

169. Conduction *is the mode by which heat is transmitted from points of high temperature to points of low temperature*

by passing from one particle to the next particle. The conduction of the heat is very gradual and as rapid through a crooked as through a straight bar.

(*a*) The power of conducting heat is called *thermal conductivity.* Among solids, metals are the best conductors both of heat and of electricity. Of the metals, silver and copper are the best, and German-silver and bismuth the poorest.

Conductivity of Liquids.

Experiment 105. — Fasten a piece of ice at the bottom of an ignition tube. A loosely wound coil of soft wire that snugly fits the tube will hold it in place. Cover the ice to the depth of several inches with water. Hold the tube obliquely, and apply the flame of a lamp below the upper part of the water. The water there may be made to boil without melting the ice below. Instead of using ice and water, pack the tube full of moist snow if you can get it.

170. Conductivity of Fluids. — Water has a very low conductivity, a fact that applies to liquids generally. The one marked exception to this rule is the liquid metal, mercury. The conductivity of copper is about five hundred times that of water. Gases have still less, if any, thermal conductivity.

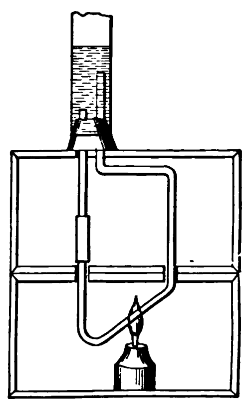

FIG. 118.

Fluid Currents caused by Heat.

Experiment 106. — With a lamp chimney or other large glass tube, a perforated cork, two pieces of glass tubing 4 and 15 inches long respectively, a bit of rubber tubing, a small lamp or a candle, and two coverless crayon boxes, arrange apparatus as shown in Fig. 118. Partly fill the apparatus with water, and add a small quantity of fine paper raspings, or of a paste made by moistening some aniline dye with a drop of water. Carefully heat the tube, as shown in the figure, and explain any observed movement of the water.

Experiment 107. — Cut a square of stiff writing paper, 15 cm. on each edge, and draw its diagonals. From the four corners, cut the paper along the diagonals to within 1.5 cm. of the middle of the square. From the corners, bring four alternate paper tips together and thrust a pin through them and the middle of the square and into the end of a penholder or lead pencil. Hold the paper wind-wheel thus made over a stove or metal plate that is very hot, the wooden handle being vertical and above the paper. One of the components into which the force of the ascending current of heated air is resolved sets the wheel in rotation.

171. Convection. — When a portion of a fluid is heated above the temperature of the surrounding portions, it expands and rises, the cooler and heavier portions of the fluid rushing in from the sides and descending from higher points. In this way, all the fluid becomes heated. *This mode of transferring heat by the mechanical motion of heated fluids is called convection*, and the currents thus established are called convection currents.

(*a*) Convection currents are applied to the heating of houses, etc., by hot-water pipes or hot-air furnaces, and constitute the basis of the most common forms of house and mine ventilation, the draft of chimneys, etc. The Gulf Stream and the trade-winds are grand convection currents.

III. EFFECTS OF HEAT.

172. Expansion is the first visible effect of heat upon bodies.

Expansion of Solids.

Experiment 108. — Provide a ring (or a sheet of tin with a hole cut in it) and a metal ball that, at the ordinary temperature, will just pass through the opening. Heat the ball and it will no longer pass through.

Experiment 109. — Support a slender flat iron bar about 50 cm. long upon two blocks as shown in Fig. 119. Place a heavy weight

upon one end of the rod, as at A, and a glass plate under the other end, as at B. (Instead of the block and weight at A, that end of the rod may be gripped in a vise.) Stick the point of a fine sewing needle into a straw pointer, and place the needle between the glass plate and the iron rod so that if the rod moves lengthwise it will roll the needle along the plate and move the end of the straw pointer along a graduated arc on a piece of cardboard placed as shown in the figure. Heat the rod with a Bunsen burner or an alcohol lamp. The rod expands, rolls the needle, and moves the pointer along the scale. Remove the lamp; as the rod cools, the pointer comes back to its original position.

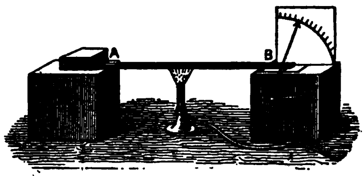

FIG. 119.

173. Expansion of Solids. — Almost without exception, solids expand when heated and contract when cooled, the amount of expansion varying with the increase of the temperature and the nature of the substance.

(*a*) The energy of the expansion and contraction of solids is very great and enables many industrial applications.

Expansion of Fluids.

Experiment 110. — Close by fusion one end of each of three similar glass tubes, 15 or 20 cm. long. Put water into one, alcohol into another, and glycerin into the third, using equal quantities of the liquids. Place the three tubes in a vessel of hot water and notice that the liquids expand unequally.

Experiment 111. — Close a bottle with a cock through which passes a glass tube of small bore and about 30 cm. long. Warm the bottle between the hands, and place a drop of ink at the end of the tube. As the air in the bottle contracts, the ink will move down the tube, forming a liquid index. By heating or cooling the bottle, the index may be made to move up or down.

Experiment 112. — Pour recently boiled water into the apparatus used in Experiment 111, until the tube is half full. Pack the bottle

in a mixture of salt and finely broken ice. Observe the liquid level in the tube. The water contracts, then expands, then freezes and expands.

174. Expansion of Fluids. — Liquids and gases expand when heated, and contract when cooled, the amount of expansion varying with the increase of temperature. In the case of liquids, the amount of expansion also varies with the nature of the substance. The rate of expansion is practically the same for all gases, and greater than it is for solids or liquids.

(*a*) Substances that crystallize on cooling, expand as they approach the temperature of solidification; i.e., a given quantity of matter occupies more space when it has a crystalline structure than it does when it has a liquid form. Ice is a good example of such a substance.

175. Coefficient of Expansion. — *The elongation per unit of length for each degree that the temperature is raised above* 0°, *is called the coefficient of linear expansion.* Similarly, *the increase in volume per unit of volume for a change of one degree of the temperature, is called the coefficient of cubical expansion.*

(*a*) For solids, the coefficient is nearly constant for different temperatures. For liquids, the coefficient is more variable. For gases under constant pressure, the coefficient is nearly constant, with a value of $\frac{1}{273}$ or 0.00366. As water is heated from 0° to 4°, it gradually contracts, so that 4° is the temperature of maximum density for water. As the temperature is raised above 4°, the water expands, slightly at first, but more and more rapidly as it approaches the boiling-point.

EXERCISES.

1. Why does oil-cloth on a cold floor feel colder to bare feet than carpet does, both being at the same temperature?
2. Why is water heated more quickly when placed over a fire than when placed under one?

3. Why do wheelwrights heat the tires of wheels before setting them?

4. Why is at least one end of a long iron bridge generally supported upon rollers?

5. What is the temperature of the surface water of a pond that is just about to freeze? Of the water at the bottom of the pond?

6. A certain quantity of gas is measured at 0°. To what temperature must it be heated, the pressure being constant, so that its volume may be doubled?

7. A mass of air at 0°, and under an atmospheric pressure of 30 inches, measures 100 cubic inches; what will be its volume at 40°, under a pressure of 28 inches?

Solution: — First suppose the pressure to change from 30 inches to 28 inches. The air will expand, the two volumes being in the ratio of 28 to 30 (§ 117). 100 cu. in. $\times \frac{30}{28} = 107\frac{1}{7}$ cu. in. Next, suppose the temperature to change from 0° to 40°. The expansion will be $\frac{40}{273}$ of the volume at 0°; the volume of the air at 40° will be $1\frac{40}{273}$ times its volume at 0°.

$107\frac{1}{7} \times 1\frac{40}{273} = 122\frac{536}{637}$. *Ans.* $122\frac{536}{637}$ cu. in.

Alternate Solution: — $\left.\begin{matrix} 28:30 \\ 273:273+40 \end{matrix}\right\} :: 100:x.$

8. At 150°, what will be the volume of a gas that measures 10 cu. cm. at 15°?

$273 + 15 : 273 + 150 :: 10 : x.$ *Ans.* 14.69 cu. cm.

9. If 100 cu. cm. of hydrogen is measured at 100°, what will be the volume of the gas at − 100°? *Ans.* 46.37 cu. cm.

10. A gas measures 98 cu. cm. at 185° F. What will it measure at 10° C. under the same pressure? *Ans.* 77.47 cu. cm.

11. A liter of air is measured at 0° and 760 mm. What volume will it occupy at 740 mm. and 15.5°? *Ans.* 1,085.34 cu. cm.

12. The bulb and tube of an air thermometer were filled with boiling water. The bulb being placed in water that contained ice, the level of the water in the tube fell for a time and then rose. Explain.

Liquefaction.

Experiment 113. — Place snow or finely broken ice and a thermometer in a vessel of water. The thermometer will fall to the freezing-point, but no further. Apply heat, so as to melt the ice very slowly, and stir the mixture constantly. The temperature does not rise until

all of the ice is melted, or it rises so little that we may feel sure that there would be no rise if each particle of water could be kept in contact with a particle of ice.

Experiment 114. — Put a little water into a beaker, and determine its temperature. Add a small quantity of sodium sulphate, and stir with a thermometer. Notice the fall of temperature during the process of solution. Repeat Experiment 13.

176. The Liquefaction of a solid is effected by fusion or by solution. In either case, heat is required to overcome the force of cohesion, and disappears in the process.

(*a*) The action of freezing-mixtures, e.g., one weight of salt and two or three of snow or pounded ice, depends upon the fact that heat is absorbed or disappears in the solution of solids.

Solidification.

Experiment 115. — Place a thermometer in a small glass vessel containing water at 30°, and a second thermometer in a large bath of mercury at – 10°. Immerse the glass vessel in the mercury. The temperature of the water gradually falls to 0°, when the water begins to freeze and its temperature becomes constant. The temperature of the mercury rises while the water is freezing.

177. Solidification. — When a liquid changes to a solid, the energy that was employed in maintaining freedom of molecular motion against the force of cohesion is released and appears as heat. The amount of heat that reappears during solidification is the same as that which disappears during liquefaction.

Melting-Point.

Experiment 116. — Close one end of a small glass tube by fusion. Place the tube in hot water and drop small bits of paraffin wax into the tube until it is filled. Notice that the melted wax is transparent. Remove the tube from the water, and, as the wax solidifies, notice any change in transparency or volume. With rubber bands, or in any other convenient way, fasten the tube to a thermometer and place both in a beaker of cool water. Gradually heat the water, stirring it with the thermometer, and carefully noting the temperature at which

the wax becomes transparent, i.e., melts. Allow the water to cool, and carefully note the temperature at which the wax becomes opaque. Find the mean of the two temperatures and record it as the melting-point of paraffin wax.

178. Laws of Fusion. — (1) *A solid begins to melt at a certain temperature that is invariable for a given substance under constant pressure. This temperature is called the melting-point of that substance. In cooling, such liquids solidify at the melting-point.*

(2) *The temperature of a melting solid or of a solidifying liquid remains at the melting-point until the change of condition is completed.*

(3) *Substances that contract on melting, as ice does, have their melting-points lowered by pressure, and vice versa.*

(*a*) It is possible to reduce the temperature of a liquid below the melting-point without solidification, but when solidification does begin, the temperature quickly rises to the melting-point.

Vaporization.

Experiment 117. — Wet a block of wood and place a watch-crystal upon it. A film of water may be seen under the central part of the glass. Half fill the crystal with sulphuric ether, and evaporate it rapidly by blowing over its surface a stream of air from a small bellows. So much heat disappears that the watch-crystal is frozen to the wooden block.

179. Vaporization *is the process of converting a substance, especially a liquid, into a vapor.* This change of condition may be effected by an addition of heat, or by a diminution of pressure, or both. When it takes place slowly and quietly, the process is called *evaporation.* When it takes place so rapidly that the liquid mass is visibly agitated by the formation of vapor bubbles within it, the process is called *ebullition.* The heat that produces the change of condition disappears in the process.

180. Condensation. — The liquefaction of gases and vapors is effected by a withdrawal of heat or by an increase of pressure, or both. In either case, the energy that was employed in maintaining the aëriform condition is released and appears as heat. The amount of heat that reappears during liquefaction is the same as that which disappears during vaporization.

Boiling-Point.

Experiment 118. — In a beaker half full of water, place a thermometer and a test-tube half filled with ether. Heat the water. When the thermometer shows a temperature of about 60°, the ether will begin to boil. The water will not boil until the temperature rises to 100°. The temperature will not rise beyond this point.

FIG. 120.

Experiment 119. — When the water used in Experiment 118 has partly cooled, dissolve in it as much common salt as possible, heat it again, and notice that it does not boil until the temperature is noticeably higher than before.

181. Laws of Ebullition. — (1) *A liquid begins to boil at a temperature that is invariable for a given substance under constant conditions. This temperature is called the boiling-point of that substance. In cooling, such vapors liquefy at the boiling-point.*

(2) *The temperature of the boiling liquid or of the liquefying vapor remains at the boiling-point until the change of condition is completed.*

(3) *An increase of pressure raises the boiling-point, and vice versa.*

(4) *The solution of a salt in a liquid raises its boiling-point, additional energy being required to overcome the cohesion involved in the solution.*

(*a*) It is possible to heat water above its true boiling-point without ebullition, by confining the steam and thus increasing the pressure,

but when the pressure is relieved, the superheated vapor immediately expands and its temperature is reduced.

(*b*) A drop of water on a smooth metal surface at a high temperature may rest upon a cushion of its own vapor, without coming into contact with the metal. A liquid in this *spheroidal state* is at a temperature below its boiling-point. When the metal cools so that the vapor pressure will not support the globule, the liquid comes into contact with the metal surface, and is converted into steam with great rapidity. Many boiler explosions are due to such causes.

(*c*) Whenever the boiling-point of a substance is lower than its melting-point, the substance vaporizes directly without previous liquefaction. Such a change is called *sublimation.* Carbon dioxide sublimes under any pressure less than three atmospheres. Iodine sublimes at pressures less than 90 mm. of mercury, and ice cannot be melted at a pressure of less than 4.6 mm.

Distillation.

Experiment 120. — Partly fill with strong brine a Florence flask, the cork of which carries a delivery-tube and a thermometer. Pass the delivery-tube through a "water jacket," *J*, kept cool substantially as shown in Fig. 121. Heat the liquid in the flask until it just boils, and taste the distilled water that collects in *R*.

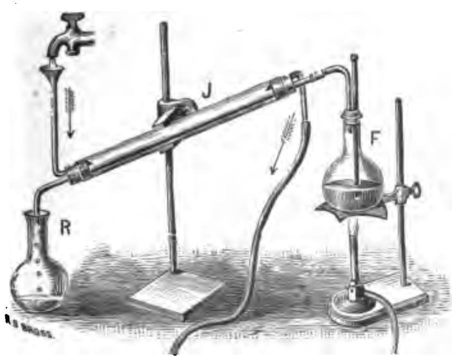

FIG. 121.

182. Distillation is the process of separating, by volatilization and subsequent condensation, a liquid from other matter with which it has been associated. It depends upon the fact that the different substances volatilize at different temperatures, and is used for various purposes.

(*a*) The most common distillation process consists in placing the distillable liquid in a metal retort, generally made of copper. When

heat is applied, vapors rise into the movable head of the retort, the neck of which is connected with a spiral tube called the *worm*.

FIG. 122.

The worm being kept cool by flowing water, the vapors of the more easily volatile constituents of the liquid pass into it, are condensed, and make their exit as a liquid, while the solid and non-volatile liquid constituents remain behind in the retort. The whole apparatus is called a *still*.

EXERCISES.

1. For the extraction of gelatin from bones by the action of hot water, a higher temperature than 100° is required. How may the water be heated sufficiently for such purposes?

2. In sugar refining, it is desirable to evaporate the liquid at a temperature considerably lower than 100°. Indicate a way in which this may be done.

3. Solid type-metal floats on melted type-metal. Does melted type-metal expand or contract on solidifying?

4. At the summit of Mount Washington, water boils at a temperature of about 94°; at the summit of Mont Blanc, at 86°; at the level of the Dead Sea, at 101°. Explain these differences.

5. If the smooth, dry surfaces of two pieces of ice are pressed together for a few seconds, the pieces will be frozen together when the pressure is removed. Explain this result, which is called *regelation*.

6. How may sea-water be made fit for drinking?

7. A drop of water may be placed on a very hot platinum plate, and the plate so held that a candle-flame may be seen between the water and the plate. Explain.

8. On a day when the doors and windows are closed, ascertain the temperature of the class-room near the ceiling and near the floor. Record your observations and explain any difference that you find.

9. On a day when the air in the class-room is warmer than that outside, stand an outer door slightly ajar, and with a candle-flame seek for inward and outward air-currents. If you find them, explain their production and show that they have an important relation to artificial ventilation.

10. Determine the boiling-point of a saturated solution of saltpeter.

11. A copper wire is passed around a block of ice and made to carry a heavy weight. The wire slowly cuts its way through the ice, which freezes up again behind the advancing wire. Explain the melting in front of the wire, and the freezing behind it.

IV. THE MEASUREMENT OF HEAT.

183. Calorimetry is the process of measuring the amount of heat that a body absorbs or gives out in passing through a change of temperature or a change of physical condition.

184. A Thermal Unit, *or a heat-unit, is the quantity of heat required to raise the temperature of unit mass of water one degree.* The unit most commonly used is *the quantity of heat required to raise the temperature of one gram of water from 0° to 1°. This water-gram-degree unit is called a therm, or a small calory.*

(*a*) A large calory is the quantity of heat required to raise the temperature of a kilogram of water from 0° to 1°. Unless otherwise specified, the calory mentioned in this book is the small calory.

185. Latent Heat. — In considering changes of condition of matter, we have spoken of the disappearance and reappearance of heat. When heat thus disappears, molecular kinetic energy is transformed into the potential form; when it reappears, the reverse transformation takes place. Because this molecular kinetic energy affects temperature, it is called *sensible heat.* Because this molecular potential energy does not affect temperature, it is called *latent heat.*

Latent Heat of Fusion.

Experiment 121. — Add a kilogram of finely broken ice (0°) to a kilogram of water at 80°. The ice will melt, and the temperature of

the two kilograms of water will be about 0°. The 80,000 calories given out by the hot water were used in simply melting the ice.

186. The Latent Heat of Fusion *of a substance is the quantity of heat that is required to melt one gram of the substance without raising its temperature.* The latent heat of fusion of ice is about eighty calories.

(*a*) The heat required to melt any weight of ice would warm 80 times that weight of water one degree, or the same weight of water 80 degrees, provided there was no change of physical condition.

Latent Heat of Vaporization.

Experiment 122. — To the end of the delivery-tube of a Florence flask containing water, attach a "trap" like that shown in Fig. 123, so that the water that condenses in the delivery-tube may be retained in the trap. (Instead of using the trap, the delivery-tube may be kept hot by a steam jacket, for which purpose the apparatus shown in Fig. 121 may be easily adapted.) Boil the water, and when steam passes rapidly from *a*, the lower tube of the trap, dip *a* into a beaker of known weight and containing water of known weight and temperature. The temperature of the water in the beaker should be considerably lower than that of the room, and the end of the tube that leads steam from the trap to the beaker should not dip into the water so much that the condensation of the steam may not be plainly heard. The beaker should be covered with a piece of cardboard, perforated for the admission of the tube, *a*, and of the thermometer, and should be shielded from the heat of the lamp and flask. After the flow of steam has been continued for some time, remove the beaker, stir its contents with the thermometer thoroughly, and take the temperature quickly but carefully. Ascertain the exact increase in the weight of the water in the beaker, and compute the amount of heat derived from the condensation of each gram of stem. Suppose that at the beginning of the experiment the water in the beaker weighed 400 g., and had a temperature of 0°, and that at the end of the experiment the weight was 420 g., and the temperature 30°. The 400 g. of water received 12,000 calories that came from the 20 g. of steam. In cooling from 100° to 30°, the condensed steam parted with 1,400 calories. The remaining 10,600 calories came from the latent heat of the steam;

FIG. 123.

i.e., each gram of steam at 100° gave out 530 calories in condensing to water at the same temperature. This result is subject to correction for radiation, absorption, etc.

187. The Latent Heat of Vaporization *of a substance is the quantity of heat that is required to vaporize one gram of that substance without raising its temperature.* The latent heat of the vaporization of water is about 537 calories.

(*a*) The heat required to vaporize any weight of water would warm 537 times that weight of water one degree, or *n* times that weight of water $\frac{537}{n}$ degrees, provided there was no change of physical condition.

188. The Specific Heat *of a substance is the ratio between the amount of heat required to raise the temperature of any weight of that substance one degree, and the amount of heat required to raise the temperature of the same weight of water one degree.* It indicates the number of calories absorbed or emitted by one gram of that substance while undergoing a change of one degree of temperature.

(*a*) The specific heat of hydrogen is 3.409; of ice, 0.505; of steam, 0.48; of oxygen, 0.2175; of iron, 0.1138; of lead, 0.0314. Water in its liquid form has a higher specific heat than any other known substance except hydrogen.

189. The Thermal Capacity *of a body is the number of calories required to raise the temperature one degree.* It is the product of the mass into the specific heat, and has direct reference to the amount of heat the body absorbs or gives out in passing through a given range of temperature.

EXERCISES.

1. One kilogram of water at 40°, 2 Kg. at 30°, 3 Kg. at 20°, and 4 Kg. at 10°, are thoroughly mixed. Find the temperature of the mixture. *Ans.* 20°.

2. One pound of mercury at 20° was mixed with one pound of water at 0°, and the temperature of the mixture was 0.634°. Calculate the specific heat of mercury.

3. What weight of water at 85° will just melt 15 pounds of ice at 0°? *Ans.* 14.117 pounds.

4. What weight of water at 95° will just melt 10 pounds of ice at − 10°? *Ans.* 8.947 pounds.

5. How many grams of ice at 0° can be melted by 1 g. of steam at 100°? *Ans.* 7.96 grams.

6. What temperature will be obtained by condensing 10 g. of steam at 100° in 1 Kg. of water at 0°? *Ans.* 6.3°+.

7. If 200 g. of iron at 300° is plunged into 1 Kg. of water at 0°, what will be the resulting temperature? *Ans.* 6.67°.

Solution: —

	Water.	*Iron.*
Specific heat,	1	0.1138
Weight,	1,000	200
Change of temperature,	x	$300 - x$

$$1{,}000\,x = 6{,}828 - 22.76\,x$$

8. A pound of sulphur can melt only one-fifth as much ice as a pound of water at the same temperature. What does this show concerning the specific heats of water and sulphur?

9. Tubs of water are sometimes placed in cellars to "keep the frost away" from vegetables, the freezing-point of which is a little below 0°. Explain the effect of the water in this respect.

10. The cylinder of a pump that forces air into the pneumatic tire of a bicycle is heated in the process. Explain.

11. Pour quickly, and through the shortest possible air space, 1.5 Kg. of mercury at 100°, into 500 g. of water at 0°. Stir the liquids thoroughly together with a thermometer, and, from the resultant temperature, determine the specific heat of mercury.

12. Place small and similar balls made severally of iron, copper, tin, lead, and bismuth, in a bath of linseed oil, and heat them to a temperature of 180°, or 200°. When they have all had time to acquire the temperature of the bath, wipe them dry, place them upon a cake of beeswax or paraffin wax about half an inch thick, and, from what you see, arrange the five metals in the order of their several specific heats.

V THE RELATION BETWEEN HEAT AND WORK.

Mechanical Effect of Heat.

Experiment 123. — Pass a bent glass tube through the air-tight cork of a flask half full of water, and let it dip beneath the surface of the water. Heat the flask. The heat will raise some of the water to the end of the tube.

FIG. 124.

190. Heat and Mechanical Energy. — When heat is produced, some other kind of energy disappears, and vice versa. The most important of these transformations are those between heat and mechanical energy. We are able to effect a total conversion of mechanical energy into heat, but we are not able to bring about a total conversion of heat into mechanical energy.

191. Joule's Principle. — *The disappearance of a definite amount of mechanical energy is accompanied by the production of an equivalent amount of heat.*

192. The Mechanical Equivalent of Heat *signifies the numerical relation between work-units and equivalent heat-units.*

(*a*) The quantity of heat that will raise the temperature of one pound of water one Fahrenheit degree is equivalent to about 778 foot-pounds. For centigrade degrees the equivalent is 1.8 times as great, or about 1,400 foot-pounds. For centigrade degrees the equivalent of a calory is about 427 gram-meters, or 4.2×10^7 ergs.

193. The Heat Equivalent of Chemical Union is of practical importance in determining the values of dif-

ferent fuels. For example, the combustion of a gram of pure carbon develops 8,080 calories.

(*a*) The relative values of the several fuels mentioned are as follows: —

Hydrogen	34,462	Carbon	8,080
Petroleum . . .	12,300	Alcohol	6,850

In each case, the figures indicate that the combustion of a given weight of the substance in oxygen yields heat enough to warm so many times the same weight of water one centigrade degree, or 1.8 times that many Fahrenheit degrees.

194. The Steam-Engine is a powerful device for utilizing the energy involved in the elasticity and expansive force of steam as a motive power. It is a real heat-engine, transforming heat into mechanical energy. Its fundamentally important parts are the cylinder, piston, and slide-valve, represented in Figs. 125 and 126, in which the steam-chest is represented as being at a distance from the cylinder, simply for the purpose of making clear the communicating steam passages. The piston, *P*, is moved to and fro in the cylinder by the pressure of the steam which is applied to its two faces alternately. This alternate application of the steam pressure is effected by the slide-valve, inclosed in a steam-chest, and moved by the valve-rod, *R*. The slide-valve covers the exhaust-port, *N*, and one of the other two ports, *A* and *B*.

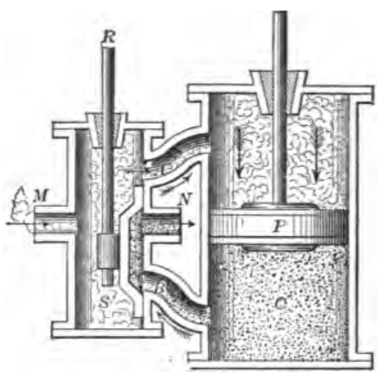

Fig. 125.

(*a*) Steam from the boiler enters the steam-chest at *M*. When the valve is in position, as shown in Fig. 125, "live" steam passes through the induction-port, *A*, into the cylinder, and pushes the piston, as indicated by the arrows, forcing out the "dead" or exhaust steam by the eduction-port, *B*, and the exhaust-port, *N*. As the piston nears the end of its journey in this direction, the valve-rod, *R*, is moved by an "eccentric," or other device, and shifts the valve into position, as shown in Fig. 126. This movement of the slide-valve changes *B* to an induction-port, by which "live" steam is admitted to the other face of the piston, pressing it in the direction indicated by the arrow, and forcing the "dead" steam out through *A* and *N*. Then the slide-valve is pushed back to its former position by the rod, *R*, and the alternating movement of the piston thus continued. The piston-rod and the valve-rod work through steam-tight packing boxes.

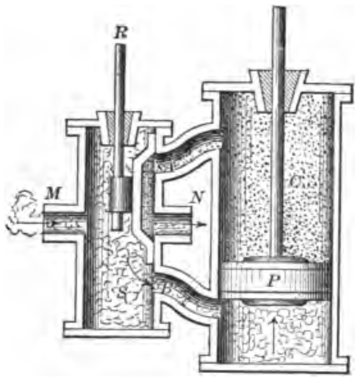

FIG. 126.

Good steam-engines are now easily accessible from nearly every school, and should be studied in detail, and by direct inspection. The action of the pitman, the crank, the crank-shaft, the fly-wheel, and the dead-points may be illustrated by almost any sewing-machine. A model showing the movements of the several parts may be bought for two or three dollars, and is desirable.

EXERCISES.

1. If a cannon ball weighing 192.96 pounds, and moving with a velocity of 2,000 feet per second, could be suddenly stopped and all its kinetic energy converted into heat, to what temperature would that heat warm 100 pounds of ice-cold water?

Solution:— $K.E. = \frac{wv^2}{2g} = \frac{192.96 \times 2000^2}{64.32} = 12{,}000{,}000$, the number of foot-pounds. Division of the number of foot-pounds by 778 gives the number of heat-units (pound-Fahrenheit) developed. This number

divided by 100 gives the number of heat-units for each pound of the water, and consequently the number of Fahrenheit degrees that it will raise the temperature. This, added to 32°, the initial temperature, will give the temperature called for.

2. A steam-engine raises 8,540 Kg. to a height of 50 m. How many calories are thus expended?

3. One gram of hydrogen is burned in oxygen. To what temperature would a kilogram of water at 0° be raised by the combustion?

4. From what height must a block of ice at 0° fall that the heat generated by its collision with the earth would just melt it if all of the heat was utilized for that purpose?

5. Show that to raise the temperature of a pound of iron from 0° to 100° requires more energy than to raise 7 tons of iron a foot high.

6. To what height could a ton weight be raised by utilizing all the heat produced by burning 5 pounds of pure carbon?

Ans. 28,280 feet.

CHAPTER V.

RADIANT ENERGY: ETHER PHYSICS.

I. NATURE OF RADIATION.

195. The Ether. — Physicists generally are of the opinion that all space is filled with an incompressible medium of extreme tenuity and elasticity. *This hypothetical medium is called the ether.* See § 9.

(*a*) The ether is regarded as an incompressible substance pervading all space and penetrating between the molecules of all ordinary matter which are embedded in it and connected with one another by its means.

196. Radiant Energy. — Since the ether fills all intermolecular spaces, the vibrating molecules of a body must communicate their motion to it. The ether-waves thus produced are propagated with a velocity of about 186,000 miles per second. When they strike a body, they may communicate their energy to the molecules of that body, and thus increase the total energy of that body. *The transference of energy by means of periodic disturbances in the ether (without regard to the precise nature of those disturbances) is called radiation. The energy thus transferred is called radiant energy.*

197. A Ray *is a line along which radiant energy is propagated;* i.e., the straight line perpendicular to the wave-front. A collection of parallel rays is called a *beam.* A collection of converging or diverging rays is called a *pencil.*

(*a*) The expressions rays, beams, and pencils, are traces of an exploded theory. So far as they pertain to the wave theory, they are convenient conceptions, nothing more.

198. Incident Radiation may be transmitted, reflected, or absorbed by the body upon which it falls. When a body absorbs radiant energy, it is heated thereby.

Recognition of Radiant Energy.

Experiment 124. — Take a white-hot poker into a dark room. You readily attribute the heat and light to the energy radiated by the poker. The light gradually becomes reddish, and finally fades from view. There is a continuous change from the emission of white light and much heat to that of no light and less heat.

199. Radiant Energy is Recognized by its phenomena, which may be classified as luminous, thermal, and chemical.

(*a*) Not even in theory can we assign limits to the length of the ether undulations. Some of these waves are competent to excite the optic nerve and to produce vision; some are not. The difference is one of wave-length only. Most of the properties and phenomena of radiant energy are most conveniently studied by luminous effects, which constitute the chief subject-matter of this chapter.

II. LIGHT: VELOCITY AND INTENSITY.

200. Light. — *The portion of radiant energy that is capable of producing the effect of vision constitutes light.*

(*a*) The longest ether-wave yet recognized is $3{,}000 \times 10^{-6}$ cm.; the shortest is 18.5×10^{-6} cm. These wave-lengths correspond respectively to vibration-frequencies of 10×10^{12} and $1{,}622 \times 10^{12}$, a range of more than seven octaves. The radiations that constitute light lie within the comparatively narrow limits of 7.6×10^{-5} cm. and 3.9×10^{-5} cm. These wave-lengths correspond to vibration-frequencies of 392×10^{12} and 757×10^{12}, a range of little more than one octave.

201. Visible Bodies are visible because of the light that they send to the eye of the observer. This is true whether the body shines by its own or another's light, i.e., whether it is self-luminous like a "live" coal, or illuminated like a "dead" coal.

NOTE. — For many experiments in light, a darkened room is desirable. The windows should be provided with opaque curtains so arranged that the sunlight may be quickly and completely excluded from the class-room.

Rectilinear Propagation.

Experiment 125. — Provide five blocks $1\frac{1}{2} \times 2\frac{1}{2} \times 3\frac{1}{2}$ inches, and three other pieces of wood each $\frac{1}{8} \times 3\frac{1}{2} \times 4$ inches. Place three postal cards one over the other on a board and perforate them with a stout needle about half an inch from the middle of one end. Pare off the rough edges of the holes with a sharp knife, and again pass the needle through each hole to make its edge smooth and even. Stand one of the postal cards on end against a vertical $1\frac{1}{2} \times 3\frac{1}{2}$ inch face of one of the blocks, and back it with one of the $\frac{1}{8}$ inch strips. Nail the strip and the card to the block. Make two more such screens. Place the three screens parallel to each other and with their blocks separated by two of the other blocks; the screens will be 5 inches apart. Pass a thread through the holes in the screens and carefully put it under tension to be sure that the perforations are in a straight line. If necessary, adjust the screens for that purpose. Remove the thread without disturbing the adjustment. On the exterior block, place a lighted candle of such length that its flame is at the height of the perforations in the cards. Place eye and candle so that the flame may be seen through the screen perforations. Move one of the screens a little so that the three holes are not in a straight line; the candle-flame cannot be seen as it was before.

202. Radiant Energy is Propagated *along straight lines when the medium is homogeneous, i.e., when it has a uniform composition and density.*

203. Transparency, etc. — Transparent bodies, as glass, transmit light so freely that objects may be seen through them distinctly. Translucent bodies, as oiled paper,

transmit light so imperfectly that objects seen through them appear indistinct. Opaque bodies cut off the light entirely, and prevent objects from being seen through them. No sharp line of separation can be drawn between these classes.

Shadows.

Experiment 126. — Coat with asphaltum varnish the lower half of the outer surface of the chimney of a lamp that has a large flat flame. At the height of the flame, scrape the varnish from a spot 3 or 4 mm. in diameter. Place the chimney on the lighted lamp with the clear spot opposite the middle of a screen of light-colored paper and about 2 m. from it. Instead of being varnished, the chimney may be smoked, or surrounded by a hollow cylinder of asbestos paper in which a hole has been cut at the proper height. Hang a croquet ball midway between the lamp and the screen. If the room is not darkened, place the ball and the screen between the lamp and the window. Prick a pin-hole through the darkened section of the screen and look through it toward the lamp. From the further side of the screen, prick a series of such holes about an inch apart and in a straight line, looking through each hole before another is pricked. When you have pricked a hole through which you can see the luminous spot on the lamp-chimney, examine the other side of the screen and notice that the pin-hole is outside the darkened section.

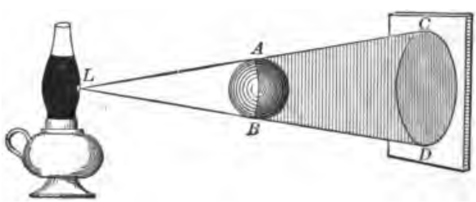

FIG. 127.

Experiment 127. — Replace the chimney used in Experiment 126 by one that is clear, and see that the side of the flame is turned toward the ball. Examine the darkened section on the screen and notice that its central disk is equally dark in all its parts, and surrounded by a ring of varying darkness. Beginning at the middle of the disk, prick pin-holes as before, examining each in succession, and avoiding those pricked in Experiment 126. Notice that you cannot see the flame through any hole in the central disk, that you

can see part of the flame through any hole in the annular space, and that you can see the whole of the flame through any hole outside the annular space.

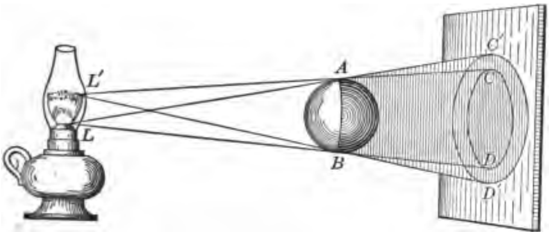

FIG. 128.

204. A Shadow *is the darkened space from which an opaque body cuts off light.* If the source of light has considerable magnitude there will be a region of complete shadow, called the *umbra*, surrounded by a partial shadow, called the *penumbra.* No light enters the umbra; the penumbra receives light from a luminous surface.

205. An Image *is an optical counterpart of an object* and may be formed in several ways. When the light actually comes from the image to the eye, the image is *real.* Such an image may be received on a screen. When the light seems to come from the image to the eye but does not, the image is *virtual.* All virtual images are optical illusions.

Inverted Images.

Experiment 128. — Place the opened end of an empty tin fruit-can upon a hot stove and leave it there just long enough to melt off the mutilated cover. Make a good-sized nail-hole at the center of the other end. Cover the nail-hole with tin-foil, and the other end of the can with thin tracing cloth or paper. Prick a pin-hole in the tin-foil, and turn it toward a candle-flame. Upon the paper may be seen an inverted image the size of which will depend upon the distance of the flame from the pin-hole. The image will be seen more plainly if the room is darkened, or a dark cloth used (after the manner of a photographer) to shut the outside light from the eyes and the screen.

206. Images by Apertures. — If light from a highly luminous body is admitted through a small hole to a darkened room, and there received upon a white screen, it will form an inverted image of the object.

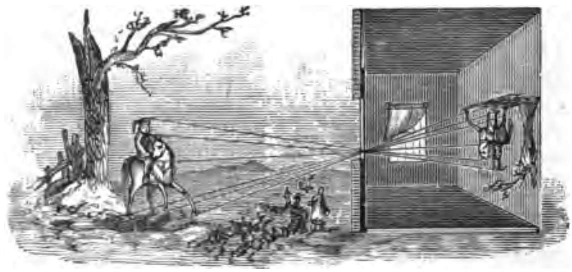

FIG. 129.

(*a*) As the rays are straight lines, they cross at the aperture; hence, the inversion of the image. The darkened room constitutes a *camera obscura* of simple form. The image of the school playground at recess is very interesting, and is easily produced.

207. The Velocity of Light *is about* 186,000 *miles* (3×10^{10} cm.) *per second.* For terrestrial distances, the passage of light is, therefore, practically instantaneous.

(*a*) The nearest of Jupiter's satellites passes within the shadow of that planet at equal intervals. But, as observed from the earth, the intervals are not equal, they being longer while the earth is passing from *E* to *E′* than they are while the earth is passing over the other half of its orbit, *E′* to *E*. Observations show that it requires 16 min. 36 sec. for light to pass over the diameter of the earth's orbit, from *E* to *E′*. This distance being approximately known, the velocity of light

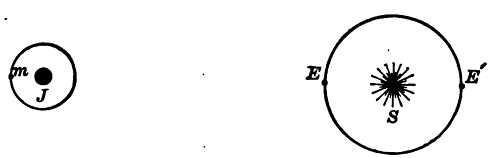

FIG. 130.

is easily computed. The velocity of light has been measured by other means, giving results that agree substantially with that above recorded.

Intensity of Illumination.

Experiment 129. — Make three cardboard screens, A, B, and C, respectively 5 cm., 12 cm., and 17 cm. on a side. Draw a line parallel to each edge of B and C, and at a distance of 1 cm. therefrom, thus inscribing squares 10 cm. and 15 cm. on a side. Divide the smaller inscribed square into four squares, each the size of A, and the larger inscribed square into nine such squares. Mount the three screens so that they stand upright with their middle points at the height of the cleared spot on the lamp-chimney used in Experiment

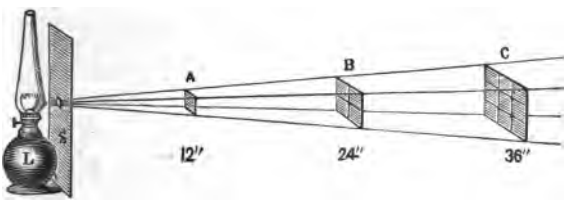

FIG. 131.

126. The screens may be conveniently supported by soft-wood rods, each having a fine slit sawed in one end and a sewing-needle thrust halfway into the other end. Place A about 30 cm. from the chimney. Set C parallel to A and at such a distance that the shadow of A just covers its nine squares. Then place B so that the shadow of A just covers its four squares. Determine the relative distances of A, B, and C from the source of light. Remove A and notice that the light that previously fell upon it now falls upon B. Remove the second screen and notice that the light that previously fell upon A and B now falls upon C.

208. The Intensity of Radiation that falls upon a surface —

(1) *Varies inversely as the square of the distance between this surface and the source of radiation.*

(2) *Varies with the angle that the incident radiation*

makes with this surface, being at a maximum when the surface is perpendicular to the direction of propagation.

(*a*) In Experiment 129, the light that fell upon *A* was diffused over four times the area at *B*, at twice the distance; and nine times the area at *C*, at three times the distance. With the same quantity of light diffused over nine times the area, the intensity of the illumination, i.e., the quantity of light per unit of surface, is only $\frac{1}{9}$ as great.

Photometry.

Experiment 130. — Arrange apparatus in a darkened room as shown in Fig. 132, where *S* represents a screen of white paper or cardboard,

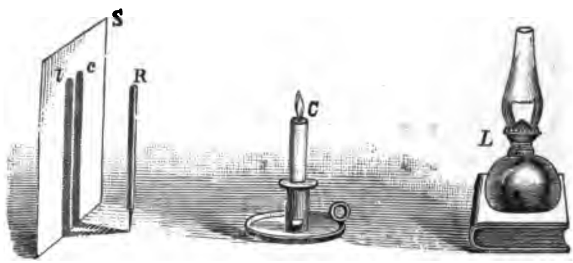

FIG. 132.

and *R*, a small rod placed upright a few inches from *S* (a cheap pen and pen-holder, or a lead pencil held by a bit of wax on the table will answer). On the table-top, draw a line through the foot of *R* and perpendicular to the lower edge of *S*. Place the candle on one side of this line and about 20 inches from *S*. Place the lamp on the other side of the line and at such a distance that the two shadows upon *S* nearly touch and are of equal darkness. The two flames should be at the same level and at equal angular distances from the line drawn on the table-top. The flat lamp-wick should stand diagonally to *S*. If the distance from *l* to *L* is twice that from *c* to *C*, then *L* is four times as powerful a light as *C*; if the distance is three times as far, *L* is nine times as powerful. Apparatus thus used constitutes a *Rumford photometer.*

Experiment 131. — Drop some melted paraffin upon a piece of heavy unglazed white paper, making a spot about an inch in diameter.

Remove the excess of paraffin with a knife, and heat the spot with a flat-iron or can of water. Support the paper as a vertical screen. Place a lighted standard candle (see § 208) at one end of a table, and a lamp or gas-flame at the other end. Place the screen between them, and arrange the pieces so that the middle points of the candle-flame, the translucent disk, and the lamp-flame are in a straight line that is perpendicular to the screen. If the lamp-flame is flat, set it diagonally to the screen. Move the screen along the line between the candle and the lamp until its two sides are equally illuminated; i.e., until the paraffined spot is invisible, or as nearly so as possible. Find the ratio between the distances of candle and lamp from the screen, and square the ratio to find the candle-power of the lamp. Apparatus thus used constitutes a *Bunsen photometer.*

209. Photometry is the measurement of the relative amounts of light emitted by different sources. The standard in general use is the light given by a sperm candle (of the size known as "sixes") when burning 120 grains per hour. The result is expressed by saying that the light tested has so many candle-power.

EXERCISES.

1. Describe the shadow cast by a wooden ball (*a*) when the source of light is a luminous point; (*b*) when the source of light is a white-hot iron ball smaller than the wooden ball; (*c*) when it is of the same size; (*d*) when it is larger.

2. Do sound waves or water waves the more closely resemble waves of light? Why?

3. A coin is held 5 feet from a wall and parallel to it. A luminous point, 15 inches from the coin, throws a shadow of it upon the wall. How does the size of the shadow compare with that of the coin?

4. An opaque screen, 3 inches square, is held 12 inches in front of one eye; the other eye is shut; the screen is parallel with a wall 100 feet distant. What area on the wall may be concealed by the screen?

5. A standard candle is 2 feet and a lamp is 6 feet from a wall. The shadows that they cast on the wall are of equal intensity. What is the candle-power of the lamp?

6. An electric arc lamp 100 feet north of me and one 200 feet south

of me illuminate opposite sides of a sheet of paper in my hand and render invisible a grease spot on the paper. How do the illuminating powers of the lamps compare?

7. If you hold a sheet of paper with a greased spot on it between you and the light, the spot will look lighter than the rest of the sheet. Why is this?

8. If you hold the sheet in front of you when you are turned away from the light, the spot will look darker than the rest of the sheet. Why is this?

9. Study the shadows cast by an electric arc lamp, and write a very brief description of the penumbra of the shadows.

III. REFLECTION OF RADIANT ENERGY.

A Simple Reflector.

Experiment 132.—About two feet from an air or other sensitive thermometer, place an inverted flower-pot. Midway between the two, place a board or glass screen that reaches from the table to a height of several inches above the bulb of the thermometer. Upon the flower-pot, place a very hot brick. Notice that the heat of the brick has little effect upon the thermometer. Then hold a sheet of tin-plate over the screen so that energy radiated obliquely upward from the brick may be reflected obliquely downward toward the thermometer. By properly adjusting the position of the reflector, the thermometer may be quickly affected.

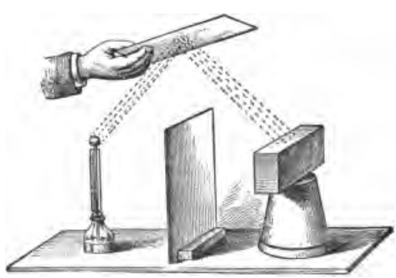

FIG. 133.

210. Reflection of Radiant Energy *is the sending back of incident ether-waves by the surface on which they fall into the medium from which they come.* The reflection may be irregular or regular.

(*a*) The reflection of radiant energy may be thus explained: Consider a beam of light as made up of a number of ether-waves moving forward in the air and side by side, as represented by the rays A, B, and C. Imagine a plane, MN, normal to these rays, attached to the waves and moving forward with them. *Such a plane is called a wave-front.* It moves forward in a straight line, and is always perpendicular to the line of propagation. As the wave-front advances beyond MN, the ray, A, strikes the reflecting surface, RS, and is turned back into

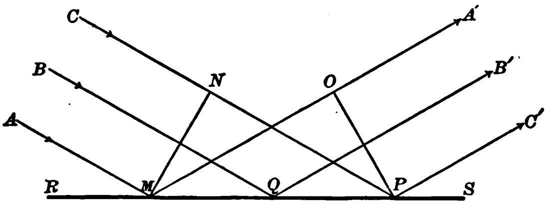

FIG. 134.

the air. By the time that the ray, C, arrives at P, the ray, A, traveling with unchanged speed, has passed over the distance, MO, equal to the distance, NP. This changes the direction of the plane that is attached to the waves, and sets it in the new position indicated by OP. Lines drawn from M, Q, and P, perpendicular to OP, will represent the new direction of propagation, i.e., the paths of reflected rays. From Fig. 134, it may easily be proved that *the angles of incidence and of reflection are equal.*

FIG. 135.

NOTE. — The class-room should be provided with a porte-lumière, which consists of a plane mirror so mounted and fitted with adjusting appliances that the direction of the light reflected from the mirror may be easily controlled. The mirror is placed on the outside of the shutter of a darkened window and operated from within, sunlight being reflected through the aperture in the shutter. The accompanying figure represents a form that may be used with a variety of accessories for projection.

Irregular Reflection.

Experiment 133. — Let a beam of light pass through an opening in the shutter of a darkened room, and fall upon a sheet of drawing paper lying on the table-top. The light will be scattered, and will illuminate the room. With a hand mirror, reflect the beam downward into a tumbler of water into which a teaspoonful of milk has been stirred. The milky water will scatter the light, and illuminate the room as if it was self-luminous.

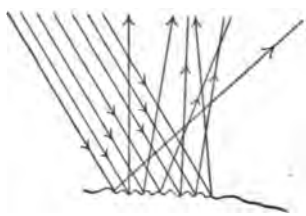

Fig. 136.

211. Irregular Reflection or Diffusion results from the incidence of radiant energy upon an irregular surface, as is illustrated by Fig. 136. Bodies are made visible to the eye mainly by the light that they thus diffuse.

Regular Reflection.

Experiment 134. — Repeat Experiment 133, allowing the beam of light to fall upon a mirror instead of drawing paper. Most of the light will be reflected in a definite direction, and will brilliantly illuminate a small part of the inclosing wall. Reflect the beam downward into a tumbler of clear water; the tumbler will be visible but the room will not be illuminated as it was by the milky water.

212. Regular Reflection results from the incidence of radiant energy upon a polished surface. When a beam of light falls upon a mirror, the greater part of it is reflected in a definite direction as is illustrated by Fig. 137, and forms an image of the object from which it came.

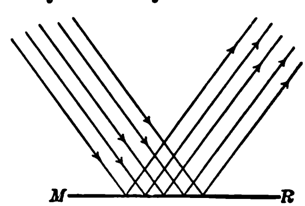

Fig. 137.

Law of Reflection.

Experiment 135. — Provide a semicircle of soft wood about 25 cm. in diameter, and on its upper surface draw radii at intervals of 10°.

Fasten a bit of looking-glass about 1 × 2 cm. at *A* and facing the curved edge of the board. The glass should be set in a notch cut in the board so that the silvered back of the mirror coincides with the diameter of the semicircle, and the middle of the mirror with the center of the semicircle. To the curved edge of the board, fasten a bright metal band that has a row of 17 holes each 4 or 5 mm. in diameter, so that one of the holes will be at the outer end of each radius marked on the board. Number the holes each way from the middle one. Hold the board so that you can look through the hole marked 0 toward the mirror and the window, and notice the image of that hole. Identify the hole by sticking a pin upright in front of it. The incident ray strikes the mirror perpendicularly and is reflected back along the same line; the angle of incidence is zero. The image of any other hole can be seen, not in this way, but through the hole that bears the corresponding number, i.e., at an equal angular distance from the radius that is perpendicular to the mirror.

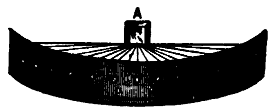

FIG. 138.

213. Law of the Reflection of Radiant Energy. — *The angle of incidence and the angle of reflection are equal, and lie in the same plane.*

214. Apparent Direction of Bodies. — Every point of a visible object sends a cone of light to the eye. The pupil of the eye is the base of the cone. *The point always appears at the real or apparent apex of the cone.* If the path of the light from the point in question to the eye is straight, the apparent position of the point is its real position. If the path is bent by reflection, or in any other manner, the point appears to be in the direction of the light as it enters the eye.

Plane Mirrors.

Experiment 136. — Place a jar of water 10 or 15 cm. back of a pane of glass placed upright on a table in a dark room. Hold a lighted candle at the same distance in front of the glass. The jar will be

seen by light transmitted through the glass. An image of the candle will be formed by light reflected by the glass. The image will be seen in the jar, giving the appearance of a candle burning in water. The same effect may be produced in the evening by partly raising a window, and holding the jar on the outside and the candle on the inside. This experiment suggests an explanation of many optical illusions.

215. Plane Mirrors. — If an object is placed before a plane mirror, a virtual image appears behind the mirror. Each point of this image seems to be as far behind the mirror as the corresponding point of the object is in front of the mirror. Hence, images seen in still, clear water are inverted.

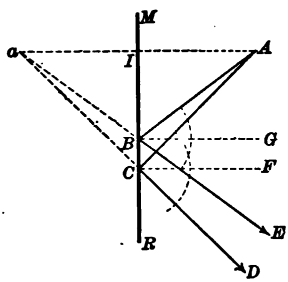

FIG. 139.

(*a*) In Fig. 139, *ABE* and *ACD* represent two luminous rays proceeding from *A* and reflected by the plane mirror, *MR*. From the figure, it may be proved geometrically that *AIB* is a right angle, and that $aI = AI$.

(*b*) The "construction for the image" is performed by locating the images of a number of well-chosen points in the surface of the object. In Fig. 140, *OB* represents an arrow in front of the mirror, *MR*. From the ends of the arrow, draw *OC* and *BD* perpendicular to the face of the mirror, and prolong them indefinitely. Take *oC* equal to *OC* and *bD* equal to *BD*. Join *o* and *b*. The image is virtual, erect (i.e., not inverted), and of the same size as the object.

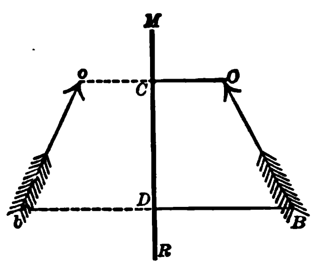

FIG. 140.

Foci.

Experiment 137. — Let a small beam of light fall perpendicularly upon a concave mirror. Strike two blackboard erasers together in

front of the mirror, and notice that the light converges at a point not far from the mirror.

216. A Focus is a point at which light converges, in which case it is called a *real focus;* or it is a point from which light appears to proceed, in which case it is called a *virtual focus.*

217. Concave Mirrors are generally spherical; i.e., the reflecting surface is a small part of the inner surface of a spherical shell. A concave mirror increases the convergence or decreases the divergence of light that falls upon it.

(*a*) *C*, the center of the sphere, is the *center of curvature* of *MR*, the mirror. *A*, the middle point of the mirror, is called the *center or vertex of the mirror.* Any straight line passing through *C* to or from the mirror is called an *axis* of the mirror. *ACX*, the axis that passes through *A*, is called the *principal axis;* all other axes are called *secondary axes.* The angle, *MCR*, is called the *aperture* of the mirror.

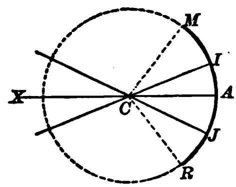

Fig. 141.

218. The Foci of Concave Mirrors may be in front of the mirror, in which case they are *real;* or they may be behind the mirror, in which case they are *virtual.*

(*a*) The location of these foci gives rise to several cases:—

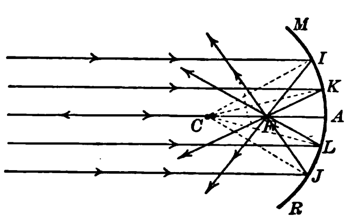

Fig. 142.

(1) When the incident rays are practically parallel to the principal axis (e.g., the sun's rays), they will be reflected, as shown in Fig. 142, to a focus at *F*, midway between *C* and *A*. This focus of rays parallel to the principal axis is called the *principal focus* of the mirror. The distance, *FA*, is called the *principal focal length*, or distance of the mirror.

(2) When the rays diverge from the center of curvature, the radiant point and the focus coincide.

(3) When the rays diverge from a point beyond the center of curvature, as from *B*, the focus is at a distance from the mirror greater than that of the principal focus, and less than that of the center of curvature, as shown in Fig. 143.

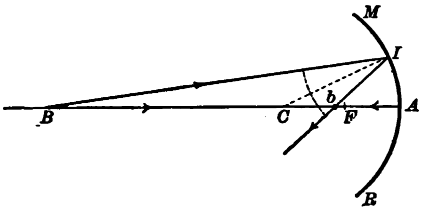

FIG. 143.

(4) When the rays diverge from a point at a distance from the mirror greater than that of the principal focus and less than that of the center of curvature, we have the converse of the third case. If the radiant point is at *b* (Fig. 143), the focus falls at *B*. Foci that are thus interchangeable are called *conjugate foci.*

(5) When the rays diverge from a point at a distance from the mirror less than that of the principal focus, the reflected rays diverge as if from a point back of the mirror. This point, *b*, is a virtual focus.

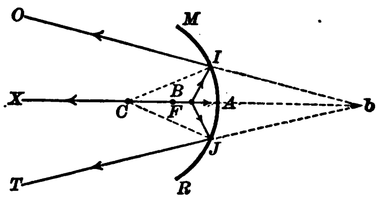

FIG. 144.

(6) When the rays diverge from the principal focus, the reflected rays are parallel and there is no focus, real or virtual. This is the converse of the first case.

(*b*) The convergence of parallel rays at the principal focus is only approximately true with a spherical mirror; it is strictly true with a parabolic mirror. In order that the difference between the spherical and the parabolic mirror may be reduced to a minimum, the aperture of the former should be small. The light from a luminous point at the focus of a parabolic mirror is reflected in truly parallel lines. The headlights of railway locomotives are thus constructed. Parabolic mirrors would be more common if they were less expensive.

Concave Mirror Images.

Experiment 138.—Place a concave mirror facing the sun, and hold a bit of paper so that its illumination by the reflected light is of the greatest intensity obtainable, thus locating the principal focus of the

mirror. Measure this focal distance. In front of the mirror, and at a distance greater than once and less than twice the focal distance, place a candle-flame. Place a tracing cloth or oiled-paper screen back of the candle, and, with a blackened card, shield it from the direct light of the candle. Adjust the positions of the candle and the screen until a good image of the former is projected on the latter.

219. Images formed by Concave Mirrors consist of the conjugate foci of the several points in the surface of the object presented to the mirror and may, therefore, be real or virtual. The "construction" may be easily performed by selecting a few determinative points, as the ends of an arrow, and determining their foci.

(*a*) The focus of each point chosen may be determined by tracing two rays from the point, and locating their real or apparent intersection after reflection by the mirror. The two rays most convenient for this purpose are the one that lies along the axis of the point, and the one that lies parallel to the principal axis of the mirror. The first of these is reflected back upon itself, and the focus must, therefore, lie in that line. The other is reflected through the principal focus, and the construction of equal angles of incidence and reflection is, therefore, unnecessary. The process is illustrated in Fig. 145.

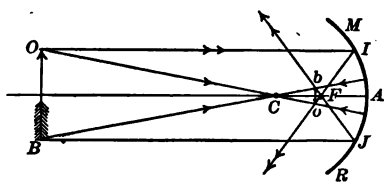

FIG. 145.

Following the order of the cases discussed in § 217, it will be found that: —

(1) When the incident rays are practically parallel (e.g., solar rays), the image is at the principal focus.

(2) When the object is at the center of curvature, the image is real, inverted, of the same size as the object, and at the center of curvature.

(3) When the object is at a distance from the mirror somewhat greater than the center of curvature, as beyond *C*, the image is real, inverted, smaller than the object, and at a distance from the mirror greater than that of *F* and less than that of *C*.

(4) When the object is at a distance from the mirror greater than

that of *F* and less than that of *C*, the image is real, inverted, larger than the object, and beyond *C*, as in Fig. 146. This is the converse of the third case.

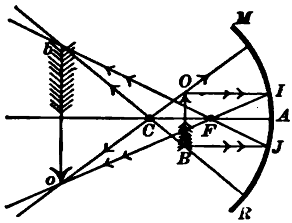

FIG. 146.

(5) When the object is at a distance from the mirror less than that of *F*, the image is virtual, erect, and larger than the object.

(6) When the object is at a distance from the mirror equal to that of *F*, the reflected rays are parallel and no image is formed. This is the converse of the first case.

220. A Convex Mirror is generally a part of the outer surface of a spherical shell. It increases the divergence, or decreases the convergence, of light that falls upon it.

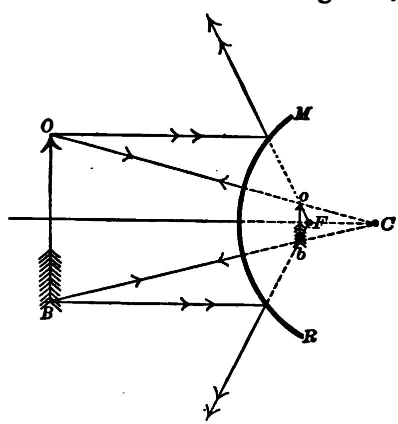

FIG. 147.

(*a*) The foci are virtual; the principal focus is midway between the center of the mirror and the center of curvature. The foci may be located and the images determined by processes similar to those used for concave mirrors, as is illustrated by Fig. 147. Such an image is erect, diminished, and virtual.

EXERCISES.

1. Copy Fig. 140, and add lines to show that the rays that form the image for the right eye of the observer are different from the rays that form the image for the left eye.

2. With a radius of 4 cm., describe ten arcs of small aperture to represent the sections of spherical concave mirrors. Mark the centers of curvature, and the principal foci, and draw the principal axes. Find the conjugate foci for points in the principal axis designated as fol-

lows: (*a*) At a distance of 1 cm. from the mirror; (*b*) 2 cm. from the mirror; (*c*) 3 cm. from the mirror; (*d*) 4 cm. from the mirror; (*e*) 6 cm. from the mirror. Make five similar constructions for points not in the principal axis. Notice that each effect is in consequence of the equality between the angle of incidence and the angle of reflection.

3. Rays parallel to the principal axis fall upon a convex mirror. Draw a diagram to show the course of the reflected rays.

4. When the sun is 30° above the horizon, its image is seen in a tranquil pool. What is the angle of reflection?

5. Given three points, *A*, *B*, and *C*, not in a straight line. Show, by a diagram, how to place a plane mirror at *C* so that light proceeding from *A* shall be reflected to *B*.

6. With a thread or fine rubber band, fasten a piece of looking-glass about 5 × 10 cm. to the vertical face of a rectangular wooden block. Balance the block and mirror upon a rule so that the face of the mirror crosses the rule at its middle. Place the eye so that the further end of the rule may be seen by looking obliquely downward and over the upper edge of the mirror. If the block back of the mirror is visible, move the mirror up until it conceals the top of the block, or use a thinner block. Adjust the mirror so that the further end of the image of the rule as seen in the mirror coincides with the end of the rule as seen over the mirror. The length of the rule is now perpendicular to the face of the mirror. Look at the images of the several divisions of the scale in front of the mirror and notice the distance of each image back of the mirror.

7. Place a cardboard screen close behind a candle-flame. Hold a concave mirror so that a sharp image of the flame is projected on the screen, making image and flame coincide as nearly as possible. Image and flame will be nearly at the center of curvature of the mirror. Describe the image. Determine the focal length of the mirror.

IV. REFRACTION OF RADIANT ENERGY.

Simple Refractors.

Experiment 139. — Hold a double-convex lens in the sun's rays, so that the bright focus on the side opposite the sun shall fall upon some easily combustible material like the tip of a friction-match. A spectacle-glass will answer, but a larger lens, like that of a reading-

glass, is desirable; the larger the lens, the better. Compare the effect of holding clean white paper at the focus, and of holding there the same paper after it has been smeared with lampblack. A lens thus used is called a *burning-glass.*

Experiment 140. — Place a coin on the bottom of a tin pan. Rest the head against the edge of a shelf or other fixed support, close one eye, and have the pan adjusted so that its side just hides the coin from view. Have water carefully poured into the pan until the coin is visible. The light coming from the coin to the eye is bent down somewhere and somehow. Measure the depth of the water in the pan. Empty and wipe the pan. Repeat the experiment using kerosene instead of water, and compare the depth of the two liquids.

221. Refraction of Radiant Energy *signifies a retardation of the ether-waves, and may be manifested by a change of direction.* Part of the light that falls on the surface of a transparent body enters it, and generally pursues therein a changed direction. *This part is said to be refracted.*

(*a*) There is a change of direction, i.e., the radiant energy is deviated, when it falls obliquely upon the interface that separates two media, as air and water, and passes from one to the other; or when it passes through a medium the density of which is not uniform, as the atmosphere.

(*b*) In Fig. 148, LA represents a ray of light propagated in air, falling obliquely upon the surface of water at A, and deviated by the water from AE to AK. Draw CD perpendicular to the refracting surface at the point of incidence. LAC is the *angle of incidence; KAD*, the *angle of refraction;* and KAE, the *angle of deviation.* From A as a center and with unity as a radius, describe a circle, and draw mn and pq perpendicular to CD. Then mn is the sine of the angle of incidence; pq is the sine of the angle of refraction.

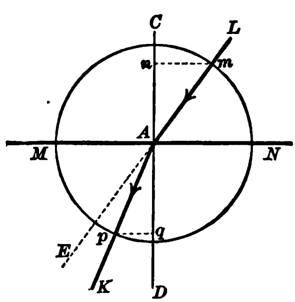

FIG. 148.

(*c*) For any two media, the quotient arising from dividing the sine of the angle of incidence by the sine of the angle of refraction is con-

stant, and is called the *index of refraction.* For ordinary purposes, the index of refraction of gases may be neglected; the index of refraction for light passing from air may be considered as $1\frac{1}{3}$ for water; $1\frac{1}{2}$ for crown-glass; and $1\frac{3}{5}$ for flint-glass.

(*d*) The determination of the direction of the refracted ray may be illustrated as follows: Let *LA* represent a ray passing from air into water at *A*. Through *A*, draw *CD* perpendicular to the refracting surface. The index of refraction for the two media is $\frac{4}{3}$. From *A* as a center and with radii that are to each other as 4 : 3, draw concentric circles. Prolong *LA* to *E*. From *v*, the intersection of *AE* with the circumference of the inner circle, draw *vp* parallel to *CD*. Through *p*, the intersection of this line with the circumference of the outer circle, draw *AK*, the line sought.

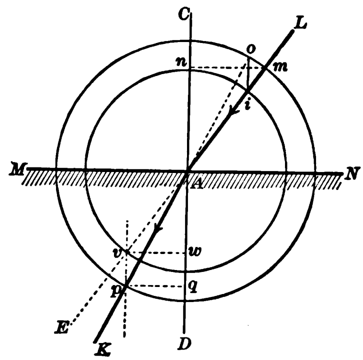

Fig. 149.

(*e*) The refraction of radiant energy may be thus explained: Consider the case of light passing from air into glass. The velocity of light in glass is less than it is in air. When a beam of light, as represented by the rays *A*, *B*, and *C*, moves forward in the air, the wave-front, *MN*, continues parallel to itself and moves forward in a straight line. As the wave-front advances beyond *MN*, the ray, *A*, enters the glass, while *B* and *C* are still in the air. The advance of *A* in the glass is retarded by the glass so that, while *C* is passing in air from *N* to *P*, *A* traverses the shorter path, *MO*.

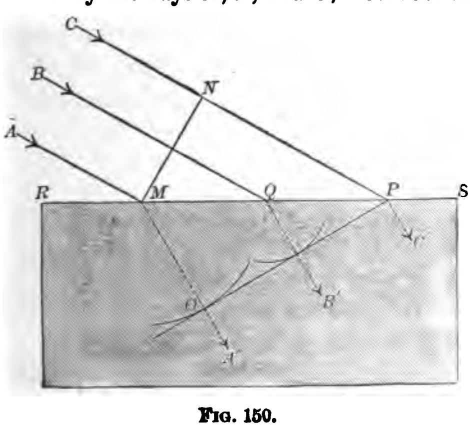

Fig. 150.

N

This retardation of A and the corresponding retardation of B change the direction of the plane that is attached to the waves, and set it in the new position indicated by OP. All of the rays having entered the glass, the wave-front again moves forward in a straight course, normal to OP, representing the new direction of propagation. *In passing into the glass the direction of the beam was changed, a direct result of a change of speed at the surface of the glass.* The beam was bent toward a perpendicular to the bounding surface, RS. When the beam emerges from the glass, similar changes will take place in inverse order, and the beam will be bent from the perpendicular to the refracting surface.

222. The Laws of Refraction. — (1) *When radiant energy passes obliquely from one medium to another of greater refractive power, the rays are bent, at the point of incidence, toward a line that is perpendicular to the surface that separates the two media.*

(2) *When radiant energy passes obliquely from one medium to another of less refractive power, the rays are bent from the perpendicular.*

223. Total Reflection. — When the angle of incidence exceeds what is called the *critical angle*, a ray of light cannot pass from a medium of higher to one of lower refractive power, as from glass or water to air; it will be totally reflected and not refracted. The critical angle for water and air is about $48\frac{1}{2}°$; for crown-glass and air, about $41°$.

Refraction by Plates.

Experiment 141. — Draw a straight line of such length that it extends both ways beyond the ends of a piece of thick plate-glass placed upon it. Look obliquely through the glass and from the side of the line, and notice the apparent displacement of the part of the line seen through the plate.

224. Refraction by Plates. — When radiant energy passes through a medium bounded by parallel planes, the refrac-

tions at the two surfaces are equal and contrary in direction. The direction after passing through the plate is parallel to the direction before entering the plate; *the rays merely suffer lateral aberration.*

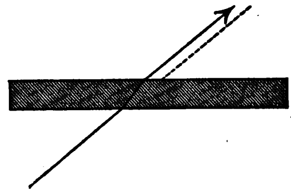

FIG. 151.

225. A Prism is a transparent body with two refracting surfaces that lie in intersecting planes. The angle formed by these planes is called the refracting angle.

(*a*) If a thin book, partly open, stands on end on a table, it represents a prism, the covers of the book representing the refracting surfaces and including the refracting angle. The table-top is perpendicular to the sides of the prism and, therefore, represents a principal plane. The triangular base of the book represents a principal section of the prism. Let *mno* represent the principal section of a prism. A ray of light from *L* is refracted at *a* and *b*. An object seen through a prism seems to be moved in the direction of the refracting angle; the rays are bent away from the refracting angle.

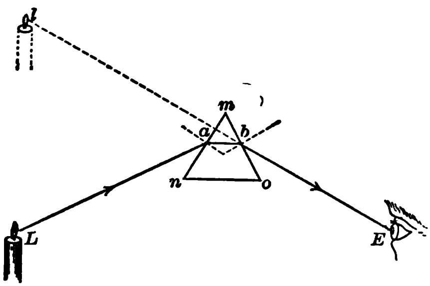

FIG. 152.

226. A Lens is a transparent body the two refracting surfaces of which are curved, or one of which is curved and the other plane. Lenses are generally made of crown-glass which is free from lead, or of flint-glass which contains lead and has greater refractive power. The curved surfaces are generally spherical.

(*a*) Lenses are converging or diverging. Each of these two classes has three varieties: —

(1) Double-convex,
(2) Plano-convex,
(3) Meniscus,
} Thicker at the middle than at the edges; converging.

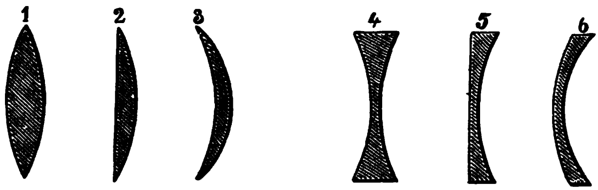

Fig. 153.

The double-convex (biconvex, or magnifying) lens may be taken as the type of these; its effects may be considered as produced by two prisms with their bases in contact.

(4) Double-concave,
(5) Plano-concave,
(6) Concavo-convex,
} Thinner at the middle than at the edges; diverging.

The double-concave (biconcave) lens may be taken as the type of these; its effects may be considered as produced by two prisms with their refracting edges in contact.

(*b*) A double-convex lens may be described as the part common to two spheres that intersect each other. The centers of the limiting spherical surfaces, as *c* and *C*, are the *centers of curvature*. The straight line, *XY*, passing through the centers of curvature is the *principal axis* of the lens. In the plano-lenses, the principal axis is a line drawn from the center of curvature normal to the plane surface. A point on the principal axis so taken that rays passing through it pierce parallel

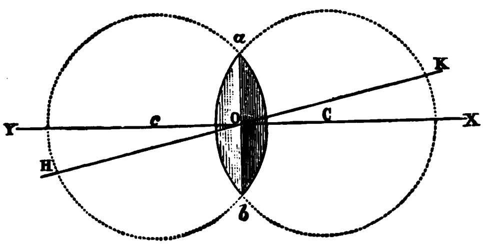

Fig. 154.

elements of the refracting surfaces is called the *optical center*. A ray passing through the optical center suffers no change of direction other than a slight lateral aberration that may be disregarded. Any straight line, other than the principal axis, passing through the optical center is a *secondary axis*.

(*c*) To trace a ray through a lens, we have only to apply the principles already explained. For example, let LN represent a glass biconvex lens (index of refraction, $\frac{3}{2}$) with centers of curvature at C and C', and AB, the incident ray. From B as a center, draw the arcs, mn and op, making the ratio of their radii equal to the index of refraction, i.e., 2 : 3. Draw the normal, $C'B$. Draw st parallel to $C'B$. Draw the straight line $tBDy$; BD is the path of the ray through the lens.

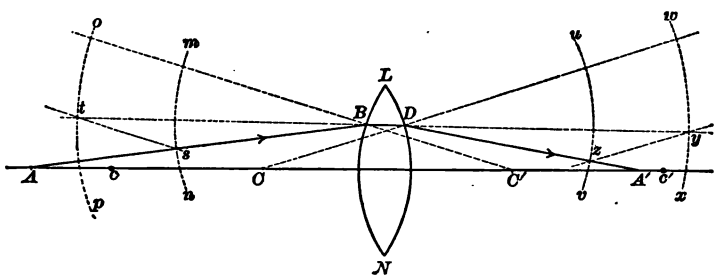

FIG. 155.

From D as a center, draw the arcs, uv and wx, using the same radii as for mn and op. Draw the normal, CD. Draw yz parallel to CD. Draw DzA', the path of the ray after emergence.

Focus of Convex Lens.

Experiment 142. — Hold one of the large lenses of an opera glass or of an optical lantern in the sun's rays. Notice the converging pencil formed by the light (after passing through the lens) as it passes through air made dusty by striking together two blackboard erasers. The focus and its distance from the lens may be seen. Measure the distance from the lens to its focus.

227. The Foci of Convex Lenses may be determined experimentally, but some of their properties are more conveniently studied by the diagrammatical tracing of

rays. To locate the focus for light diverging from any point, it is necessary to determine the point of intersection of two emergent rays. The problem is much simplified by considering the axis that passes through the point of divergence as the path of one of these rays.

(*a*) Experimental work with convex lenses develop frequent analogies to the phenomena of concave mirrors, and give rise to several cases as follows: —

(1) When the incident rays are parallel to the principal axis, their focus is called the *principal focus*. With a biconvex lens of crown-glass (index of refraction, $\frac{3}{2}$) the principal focus is at the center of curvature, i.e., the focal length of the lens is equal to the radius of curvature. With a plano-convex lens, the focal length is twice the radius of curvature. In either case, the focus is real.

(2) When the incident rays diverge from a point more than twice the focal distance from the lens, a real focus is formed on the other side of the lens, and at a distance greater than the focal length and less than twice the focal length. (See A and A', Fig. 155.)

(3) When the incident rays diverge from a point at twice the focal distance from the lens, a real focus is formed on the other side of the lens and at the same distance from it. These two points, as c and c' in Fig. 155, are called *secondary foci*.

(4) When the incident rays diverge from a point distant from the lens more than the focal length and less than twice the focal length, a real focus is formed on the other side of the lens and at a distance greater than twice the focal length. This is the converse of the second case. Two foci that are thus interchangeable, like A and A' in Fig. 155, are called *conjugate foci*. The secondary foci are conjugate.

(5) When the incident rays diverge from the principal focus, the emergent rays will be parallel, and no focus, real or virtual, will be formed. This is the converse of the first case.

(6) When the incident rays diverge from a point nearer the lens than the principal focus, the emergent rays are still diverging, and a virtual focus is formed back of the radiant point.

(7) When the incident rays are converging, a real focus is formed on the other side of the lens at a distance less than the focal length. This is the converse of the sixth case.

(*b*) Each pupil should draw a figure to illustrate each of the foregoing cases.

228. The Foci of Concave Lenses may be located by processes already studied. Such lenses have their centers of curvature, their primary and secondary axes, and their optical centers the same as convex lenses.

(*a*) Experimental work with concave lenses develop frequent analogies to the phenomena of convex mirrors, and give rise to several cases as follows:—

(1) When the incident rays are parallel to the principal axis, the emergent rays diverge as if they came from a virtual focus, which is called the principal focus. With a biconcave lens of glass (index of refraction, $\frac{3}{2}$), the principal focus is at the center of curvature. With a plano-concave lens, the focal length is twice the radius of curvature.

(2) When the incident rays are diverging, the focus is virtual and at a distance from the lens less than the focal length. As the radiant point approaches the lens, the focus also approaches the lens.

(3) When the incident rays are converging, the effects are varied according to the degree of convergence. If the point of convergence is nearer the lens than the principal focus, a real focus will be formed at a distance greater than the focal length of the lens. If the point of convergence is at the principal focus, the emergent rays will be parallel, and no focus will be formed. If the point of convergence is further from the lens than the principal focus, a virtual focus will be formed.

(*b*) Each pupil should draw a figure to illustrate each of the foregoing cases.

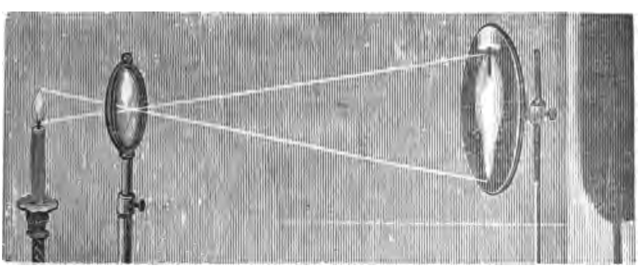

FIG. 156.

Images.

Experiment 143.— Place a candle, a convex lens of known focal length (see Experiment 142), and a screen in line as shown in Fig. 156,

the distance of the candle from the lens being a little greater than the focal length of the lens. Adjust the position of the screen until a sharply defined image of the candle is projected upon it. Place the eye back of the screen and have the screen removed; the inverted image may be seen suspended in mid-air. Burn touch-paper under the image, and notice its projection on the screen of smoke. Replace the screen first used.

Experiment 144. — With candle and screen in positions as described in Experiment 143, adjust the position of the lens so that the flame and the image of the flame are of the same size. Measure the distance of the screen from the candle, and compare a quarter of that distance with the focal length of the lens.

229. Images formed by Lenses consist of the conjugate foci of the several points in the surface of the object presented to the lens and may, therefore, be real or virtual. The construction for such images is closely analogous to the process used for images formed by mirrors.

(*a*) The focus of each point chosen may be determined by tracing two rays from the point, and locating their real or apparent intersection after emerging from the lens. The two rays most convenient for this purpose are the one that lies along the secondary axis of the

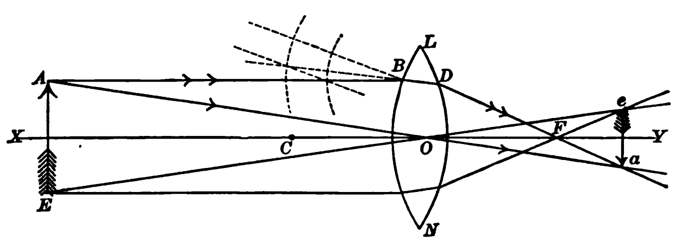

FIG. 157.

point, and the one that lies parallel to the principal axis of the lens. For example, from *A* and *E*, extremities of an arrow, draw the secondary axes, *AOa* and *EOe*. From *A*, draw *AB* parallel to the principal axis, *XY*. Determine the direction of *BD* by construction. From *D*, draw the path of the emergent ray through the principal

focus, F. It intersects the secondary axis at a, the conjugate focus of the radiant point, A. In similar manner, the conjugate focus of the point, E, may be located at e. The points, a and e, mark the extremities of the image of the object, AE.

(*b*) An examination of Fig. 157 shows that the linear dimensions of object and image are directly as their respective distances from the center of the lens; they will be virtual or real, erect or inverted, according as they are on the same side of the lens, or on opposite sides.

EXERCISES.

1. Remembering the varying density of the earth's atmosphere, draw a diagram showing that the sun may be seen before it has astronomically risen, and after the true sunset, i.e., after it has dipped below the western horizon.
2. Draw circles so that parts of their circumferences may represent the curved surface of a meniscus, a biconcave, and a concavo-convex lens.
3. Construct the critical angle for air and water.
4. Show how a beam of light may be bent at a right angle by a glass prism.
5. Trace a ray through a biconvex lens for the location of its principal focus.
6. Trace a ray through a biconcave lens for the location of its principal focus.
7. Through what point does the line joining the conjugate foci of a convex lens always pass?
8. (*a*) The focal distance of a convex lens being 6 inches, determine the position of the conjugate focus of a point 12 inches from the lens. (*b*) 18 inches from the lens.
9. The focal distance of a convex lens is 30 cm. Find the conjugate focus for a point 15 cm. from the lens.
10. If an object is placed at twice the focal distance of a convex lens, how will the length of the image compare with the length of the object?
11. Focus a spy-glass or small telescope on an object a mile or more distant. The rays coming from the object to the eye will be practically parallel. Place a lens, the focal length of which you are to measure, in front of the telescope. Place a small-type newspaper-clipping on a piece of cardboard, and look at it through the telescope and lens. Adjust the position of the cardboard so that the printing

appears distinct. Measure the distance of the cardboard from the lens. Obtain the average of several such trials. Record a discussion of the proposition that this average distance is the focal length of the lens.

V. SPECTRA, CHROMATICS, ETC.

Analysis.

Experiment 145. — Admit a sunbeam through a small opening in the shutter of a darkened room. In the path of the beam, place a prism, as shown in Fig. 158. Instead of the colorless image of the sun at E, there appears upon the white screen a many-colored band changing gradually from red at the lower end, through all the colors of the rainbow, to violet at the upper end.

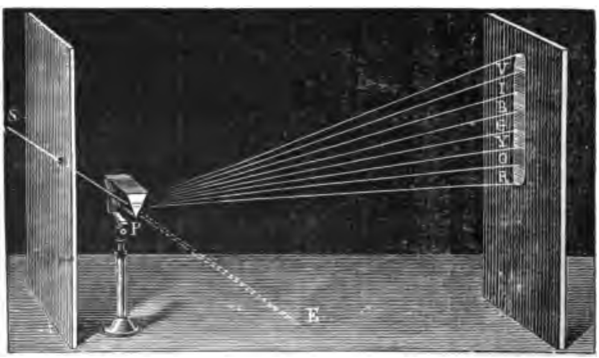

FIG. 158.

230. Dispersion. — *The separation of differently colored rays by refraction is called dispersion.* Experiment 145 shows that white or colorless light, like that of the sun, is a mixture of radiations of varying color, and that they may be separated because of their varying refrangibility.

(*a*) The differences in deviation arise from differences of wave-length, the angle of deviation increasing as the wave-length diminishes.

(*b*) A converging lens brings the focus of violet rays nearer the lens than it does the focus of red rays, because of their greater refrangibility. The images formed by such lenses are, therefore, often fringed with color. *This difference in the deviation of differently colored rays is called chromatic aberration.* A compound lens, like that shown in Fig. 159, is called *achromatic* because it forms an image that is nearly free from the fringe of color.

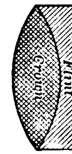

FIG. 159.

231. Spectra.— *The many-colored image of the sun projected on the screen in Experiment* 145 *is called a spectrum.* As the differently colored images of the sun overlap, the spectrum thus produced is an impure spectrum.

(*a*) These prismatic colors are generally described as violet, indigo, blue, green, yellow, orange, and red. The initial letters of these terms form the meaningless, mnemonic word "vibgyor."

Synthesis.

Experiment 146.— Let light that has been dispersed by a prism fall upon an achromatic convex lens as shown in Fig. 160. It will be refracted to a focus and recombined to form white light. Hold

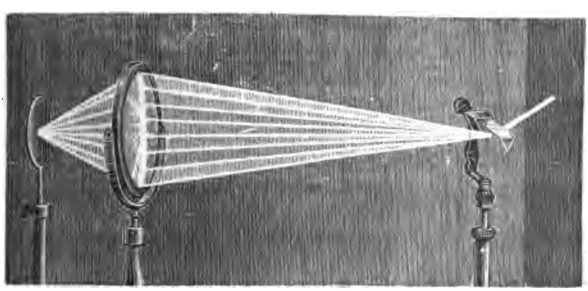

FIG. 160.

a card between the prism and the lens so as to cut off the red light, and notice the focus of what remains. Similarly cut off the violet light, and again notice the focus of what remains. A concave mirror may be used to reflect the light to a focus instead of using the lens as above described.

232. The Composition of White Light. — We have now shown, by analysis and by synthesis, that *white light is composed of the prismatic colors.*

Color.

Experiment 147. — Gradually raise the temperature of a platinum wire by an electric current. The first radiations emitted are those of "obscure heat"; i.e., they affect the nerves of general sensation only. As the temperature continues to rise, waves of shorter and shorter wave-length are added, while those previously emitted are increased in amplitude. The wire successively appears red, orange, and yellow and then becomes white hot, the light emitted being exceedingly complex.

233. Color *is a property of light, and depends upon wave-length.* Thus, the relation between color and light is the same as that between pitch and sound.

(*a*) The wave-lengths that correspond to the several prismatic colors as they appear in the solar spectrum are as follows: —

Violet,	4,059	Green,	5,271	Orange,	5,972
Indigo (violet-blue),	4,383	Yellow,	5,808	Red,	7,000
Blue (cyan-),	4,960				

These magnitudes are for the *middle points* of the several colors, and represent ten-millionths of a millimeter. Light of only one wave-length is said to be *monochromatic* or *homogeneous.*

(*b*) An incandescent body emits radiations with wave-lengths that grade imperceptibly from values less to values greater than any of those given above. When the wave-lengths are much less or much greater than those above given, the radiation is incapable of exciting vision. The visible spectrum occupies only one of the seven or more octaves of the full spectrum. The invisible spectra (ultra-violet and infra-red) have been explored with delicate thermoscopes, by photography, etc.

Color of Bodies.

Experiment 148. — Paint three narrow strips of cardboard, one vermilion-red, one emerald-green, and the other aniline-violet. Be sure that the coats are thick enough thoroughly to hide the cardboard. When dry, hold the red strip in the red of the solar spectrum; it appears red. Move it slowly through the orange and yellow; it grows

gradually darker. In the green and colors beyond, it appears black. Repeat the experiment with the other two strips, and carefully notice the effects.

Experiment 149.—Make a loosely wound ball of candle-wick; soak it in a strong solution of common salt and water; squeeze most of the brine out of the ball; place the ball in a plate, and pour alcohol over it. Take it into a dark room and ignite it. Examine objects of different colors, as strips of ribbon or cloth, by this yellow light. Only yellow objects will have their usual appearance.

234. The Color of a Body *depends upon the light that the body reflects or transmits to the eye.* Some bodies have a power that may be described as selective absorption, reflecting or transmitting light of certain wave-lengths, and absorbing the others. If the light incident upon a body has only the wave-lengths that the body absorbs, the body can send no light to the eye and, therefore, appears black.

(*a*) A red ribbon is red because it reflects light of the particular wave-length that corresponds to the sensation of redness, and absorbs the rest. A white ribbon is white because it reflects the same proportion of all the light that constitutes sunlight. A piece of blue glass is blue because it transmits or reflects light of the particular wave-length that corresponds to the sensation of blueness, and absorbs the rest. Glass that absorbs none of the incident light is colorless.

235. Complementary Colors *are any two colors the blending of which produces white light.* If the colors of the solar spectrum are divided into two parts and the colors in each part are blended, each resultant color evidently has what the other needs to make white light. Either of such colors is said to be complementary to the other.

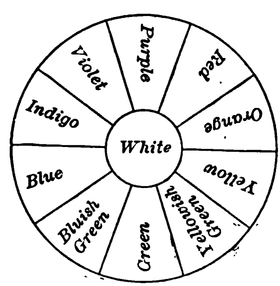

FIG. 161.

(*a*) Any two colors standing opposite each other in Fig. 161 are complementary to each other. If such colors are blended, the result-

ant is white light; if any two alternate colors are blended, the resultant will be the color that appears between them in the figure.

Pigments.

Experiment 150. — With a yellow-colored crayon, draw a broad mark on the blackboard. Along the same line, draw a similar mark, with a blue crayon. Also mix a small quantity of chrome-yellow with a like quantity of some ultramarine-blue pigment. The blending of blue and yellow colors gives a white; the blending of yellow and blue pigments gives a green.

236. Mixing Pigments is a very different thing from mixing colors. In the majority of cases, the scattering of incident light takes place not only at the surface of bodies but also at distances below the surface. In the case of pigments, most of the scattered light comes from below the surface. In Experiment 150, the yellow pigment removed most of the violet, indigo, and blue by such absorption. The blue pigment similarly removed most of the yellow, orange, and red. The radiations that escaped both were of the particular wave-length that constitutes green: —

~~vib~~g~~yor~~.

The Rainbow.

Experiment 151. — Fill a glass bulb with clear water. Cut a circular opening (somewhat smaller than the bulb) in a large sheet of cardboard. Reflect a sunbeam into a darkened room so that it shall pass through the opening in the cardboard and fall upon the water-filled bulb. Adjust the position of the bulb until circular spectra are thrown by the bulb back upon the cardboard screen.

237. A Rainbow *is a solar spectrum formed by water-drops.*

(*a*) The center of the circle of which the rainbow forms a part is in the prolongation of a line drawn from the sun through the eye of the observer. This line is called the *axis of the bow.*

The rays of sunlight incident upon the rain-drops are refracted as they enter the drop, internally reflected, and chromatically dispersed. The drop at *V* has an angular distance of 40° from *EO*, the axis of the bow, and sends only violet rays to the eye at *E*. Other drops, at the same angular distance from *EO*, send violet light to the eye and, therefore, form a violet-colored circular arc of which *OV* is the radius of curvature. Similarly, the angle of deviation for red rays is such that the drop, *R*, at an angular distance of 42° from *EO*, sends red rays to the eye of the observer. Other drops at the same angular distance send red light to the eye and, therefore, form a red-colored circular arc, of which *OR* is the radius of curvature. The primary bow, therefore, has an angular width of 2°, the other prismatic colors ranging in regular order between the violet and the red.

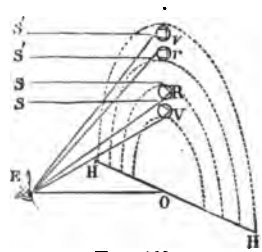

FIG. 162.

(*c*) Sometimes a secondary bow is visible outside the primary and with the colors in reversed order. This bow involves two reflections within each drop, as shown at *R* and *V*.

Pure Spectra.

Experiment 152. — Cut a very narrow slit, 2 or 3 cm. long, in a piece of tin or of tin-foil, and fasten the sheet over the opening in the shutter of a darkened room so that the slit shall be horizontal. The porte-lumière (Fig. 135) may be provided with a disk with an adjustable slit that is very convenient for such purposes as this. Hold a prism about 1.5 m. from the slit and with its edges horizontal. Looking through the prism at the slit, turn the prism about its axis until the colored image of the slit is at the least angular distance from the slit itself. The colors of the image will show with a greater distinctness than before observed.

238. A Pure Spectrum is made up of a succession of colored images with little or no overlapping. The first requisite in preventing the overlapping is that the slit be very narrow.

(*a*) A *spectroscope* is an instrument used to produce a spectrum of the light from any source, and for its study. It affords a delicate means of chemical analysis and is one of the most powerful aids to modern science. In one of its simple forms it consists of,—

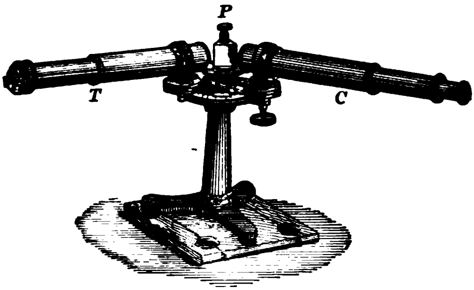

FIG. 163.

(1) A collimator, *C*, a tube with an adjustable slit with parallel edges at the outer end through which the light enters, and at the other end a collimating lens that brings the rays into a parallel beam.

(2) A prism, *P*, or a series of prisms, that receives the radiation from *C*, and disperses it, thus forming a spectrum.

(3) A telescope, *T*, through which the magnified image of the spectrum is viewed. The spectrum is received directly upon the retina of the eye and may be distinctly seen even when the radiation is feeble.

A pocket form of the spectroscope, so often called *direct-vision spectroscope*, is not very expensive, and may be made to answer for the purpose of this book.

Spectrum Analysis.

Experiment 153.—Examine a candle-flame with a spectroscope, and notice that the colored *spectrum is continuous* through all the prismatic colors. Evidently, the radiation is extremely complex.

Experiment 154.—Dip a platinum wire or a strip of asbestos into a solution of sodium chloride (common salt), and hold it in the almost colorless flame of a Bunsen burner or an alcohol lamp. The sodium vapor colors the flame yellow. Examine this sodium flame with a spectroscope, and notice that the *spectrum consists of a bright yellow line* instead of the continuous multi-colored band.

239. Spectrum Analysis.—Certain substances yield colored flames, the yellow of sodium, the lilac of potassium, etc., being familiar. The vapors of such substances

yield characteristic spectra that may be used for their identification. This method of *analyzing composite radiations, or of identifying substances by the spectra of their incandescent vapors, is called spectrum analysis.*

(*a*) As a condition necessary for the production of the spectrum, the temperature must be so high that the substance to be examined will be vaporized, diassociated, and made incandescent. Having mapped the spectra of all known substances, the presence of new lines in any spectrum would indicate the presence of a substance previously unknown. The quantity of material required for such examination is exceedingly small, a hundred-millionth of a milligram of strontium giving the spectrum characteristic of that element.

Dark-Line Spectrum.

Experiment 155. — Remove the objective from an optical lantern (§ 251). From the lantern, send a beam of electric or calcium light through a narrow vertical slit in a screen. Beyond the screen, place a double convex lens to receive the light that passes through the slit. Beyond the lens, place a prism so as to throw a spectrum on a screen still beyond. Place a Bunsen burner or an alcohol lamp between the lantern and the slit and, in its almost colorless flame, hold a bit of sodium. The metal will burn, giving an intense yellow to the flame. Notice that the yellow of the spectrum, instead of being more intensely illuminated, is marked by a *dark band.* Then hold a piece of tin between the lantern and the flame and so as to cut off the light of the lantern from the upper part of the slit. The upper part of the slit is now traversed by light from the sodium-colored flame, and the lower part of the slit by light from both the lantern and the flame. The image of the slit is inverted, and two parallel spectra are thrown on the screen. One of these is the bright-line spectrum of sodium; the other shows a dark line on a continuous spectrum. Notice that the bright line of one spectrum is in the same relative position as the dark line of the other spectrum, as if the sodium vapor absorbed light of the same refrangibility as that which it emits.

240. Kinds of Spectra. — A spectrum may be continuous or discontinuous; a discontinuous spectrum may be a bright-line spectrum or a dark-line spectrum. Dark-line

spectra are sometimes called reversed spectra, or absorption spectra.

241. The Fraunhofer Lines. — A spectrum of sunlight is crossed by dark lines, many hundreds of which have been counted and accurately mapped. The more conspicuous of these dark lines are distinguished by letters of

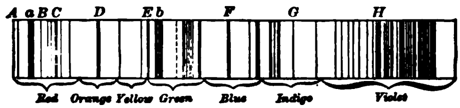

FIG. 164.

the alphabet, as shown in Fig. 164. A few of these dark lines in the solar spectrum are due to absorption in the earth's atmosphere, but by far the greater number originate in the selective absorption of the solar atmosphere itself.

(*a*) Just as the *D*-line corresponds to sodium, so the greater number of the Fraunhofer lines have been identified in the spectra of known terrestrial substances. The presence of at least thirty-six elements in the sun's atmosphere has been thus established, the absent wave-frequencies indicating the identity of the absorbing media.

242. Laws of Spectra. — (1) *Incandescent solids and liquids give continuous spectra.* This is true of vapors and gases also when they are under great pressures. The spectrum from the flame of a candle, of kerosene, or of illuminating gas is continuous, being due to the incandescent carbon particles suspended in the flame.

(2) *Incandescent rarefied vapors and gases give discontinuous spectra consisting of colored bright lines or bands.*

(3) *If light from an incandescent solid or liquid passes through a gas at a temperature lower than that of the incandescent body, the gas absorbs rays of the same degree of refrangibility as that of the rays that constitute its own spectrum.*

Thermal Effects of Radiant Energy.

Experiment 156. — Hold a pane of glass between the face and a hot stove; the glass shields the face from the heat of the stove. Hold the glass between the face and the sun; the glass does not shield the face from the heat of the sun.

243. Thermal Effects may be detected throughout the length of the visible spectrum and beyond in each direction, i.e., in the infra-red spectrum and in the ultra-violet spectrum. The infra-red or longer wave-length radiation is present in the spectrum from any hot body; the ultra-violet or shorter wave-length radiation in that from a body at a high temperature, as the incandescent carbons of an arc electric light.

(*a*) When radiant energy is considered with reference to its heating effects, it is sometimes erroneously called "radiant heat." Similarly, the radiation of the infra-red region is spoken of as "obscure heat."

(*b*) Glass, water, watery vapor, and alum transmit light, but absorb nearly all of the energy of infra-red rays. A solution of iodine in carbon disulphide absorbs luminous and transmits infra-red rays.

Absorption, etc.

Experiment 157. — Focus a sunbeam on the clear glass bulb of an air thermometer, and notice the feeble effect produced. Coat the bulb with candle soot, and repeat the experiment. Notice the greatly increased effect.

244. Radiation, Reflection, and Absorption. — Bodies differ greatly in absorbing power. A good absorber is a poor reflector. Lampblack is a substance of maximum absorbing and of minimum reflecting power. *The emission and the absorption of radiant energy go hand in hand*, good absorbers being good radiators, good reflectors being poor radiators, etc.

245. Chemical Effects may be detected throughout the length of the visible spectrum and beyond in each direc-

tion. The chemical changes upon which ordinary photography depends are most stimulated by the violet and ultra-violet rays; this, however, is not true of all chemical changes, and even infra-red photography has been accomplished.

(*a*) From one end of the spectrum to the other, the radiation differs intrinsically in wave-length only; the observed diversity of effect is due to the character of the surface upon which the radiation falls.

246. Change of Vibration-Frequency. — When solutions of certain substances, such as sulphate of quinine, are exposed to ultra-violet radiation, the solutions lower the rate of vibration to that of an opalescent blue light. *This property of lowering the vibration-frequency of ultra-violet radiation to the range of vision is called fluorescence.* Another class of substances, such as the sulphides of barium, calcium, and strontium, are luminous when carried from sunlight into a dark room and, for a long time after, present the general appearance of a hot body cooling. *This property of shining in the dark after exposure to light is called phosphorescence*, and has been utilized in the production of what are called "luminous paints." The luminous rays of an electric arc may be absorbed by a solution of iodine in carbon disulphide, and the residual infra-red rays reflected or refracted to a focus. A piece of platinum or of charcoal at such a focus of non-luminous radiation may be heated to incandescence. *This raising of the vibration-frequency of infra-red radiation to the range of vision is called calorescence.*

EXERCISES.

1. Taking the velocity of light to be 186,000 miles per second and the wave-length of green light to be 0.00002 of an inch, how many waves per second beat upon the retina of an eye exposed to green light?

2. How may the chromatic aberration caused by a simple lens be corrected?

3. What name is given to the differential deviation by refraction of rays of different wave-frequencies?

4. Why is a rainbow never seen at noon?

5. Why do not the sun's rays heat the upper atmosphere of the earth as they pass through it?

6. Show that the glass walls and roof of a greenhouse are a trap for solar heat.

7. Why is it oppressively warm when the sun shines after a summer shower?

8. Why is there greater probability of frost on a clear than on a cloudy night?

9. Explain the fact that the glass of a window may remain cold while the sun's radiations are pouring through it and heating objects in the room.

10. How can you cut out the short-wave radiations of an arc electric lamp? How can you cut out the long-wave radiations?

11. Show that the watery vapor in the atmosphere acts as a blanket for terrestrial objects.

12. Make a cubical metal vessel with edges of about 7 or 8 cm., and vertical faces made respectively of polished brass, sheet lead, bright tin-plate, and tin-plate that has been coated with lampblack. Leave a small opening in the upper face. Such a vessel is called a *Leslie cube.* Fill it with water, and bring the temperature to 10°. Place the cube 3 or 4 cm. from an air thermometer or from one bulb of a differential thermometer, and note the effect upon the thermometer. Raise the temperature successively to 20°, 30°, 40°, etc.; bring it within the same distance of the thermometer, and note the effect in each case. Record a comparison of the readings of the mercury thermometer in the cube with the indications of the air thermometer, and a clear statement of the relation between them.

13. Repeat one of the tests of Exercise 12, and then interpose a pane of window glass between the cube and the thermometer. Explain the effect produced by the screen.

14. With the same apparatus, test the absorptive powers of tin-foil, lampblack, India-ink, and white-lead by successively coating the bulb of the air thermometer with such substances.

15. Test the radiating powers of tin, lampblack, India-ink, and white-lead by successively turning faces of the Leslie cube thus coated

toward the bulb of the air thermometer, being careful that the temperature and the distance of the cube are the same in each instance. Try to find some relation between the absorbing powers and the radiating powers of these several substances.

VI. INTERFERENCE, DIFFRACTION, POLARIZATION, ETC.

Interference.

Experiment 158. — In any convenient clamp, firmly press together the centers of two pieces of clean, thick plate-glass. Look obliquely at the glass, and a beautiful play of colors will be seen surrounding the point of greatest pressure. If the glass is illuminated by the monochromatic light of a sodium flame (see Experiment 149), yellow bands separated by dark bands will be seen.

247. Interference of Light. — We have seen that two wave-motions may combine in such a way as to neutralize each other (§ 151), and that such an interference is a peculiarity of wave-motion. The fact that light may thus neutralize light is strong confirmation of the wave-theory.

(*a*) In the historical experiment of which Experiment 158 is a modification, a plano-convex lens of little curvature was pressed upon a flat piece of glass. When looked at from above, the center of the lens thus used is surrounded by rainbow-like bands of color, known as *Newton rings*. Of the light that falls vertically upon the lens, some is reflected at the curved surface, and some from the upper surface of the plate under the lens. These latter rays have to traverse twice the wedge-shaped film of air between the lens and the plate. Whenever the thickness of the air-film is such that the two sets of reflected waves unite in opposite phases, interference is the result. If the apparatus is observed by white light, and the red rays are destroyed at a certain distance from the center of the lens, the color *perceived at that distance* will be complementary to the destroyed red, and will form a circular green band. If the appa-

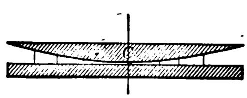

FIG. 165.

ratus is observed by red light, a dark ring will appear at the same distance. At another distance from the center of the lens, the violet rays will be destroyed, and the circular band seen at that distance will be due to the combination of the other constituent rays of the light used.

(*b*) Interference colors similarly produced by reflection are often seen in soap-bubbles, in small quantities of oil that have been spread over large sheets of water, in mica, selenite, ice, and other crystals.

(*c*) If a beam of monochromatic light is passed through a narrow slit and received upon a screen in a dark room, a series of alternately light and dark bands or "fringes" is seen; if white light is employed, a series of colored spectra is obtained. As the primary and secondary waves cut each other, they unite at some points, crest with crest, and, at other points, crest with trough. At the latter points, we have interference of light with the effects of colors produced thereby. *Such interference phenomena constitute what is called diffraction.* The halos sometimes seen around the sun and moon and street lamps are due to diffraction of light by watery globules in the atmosphere.

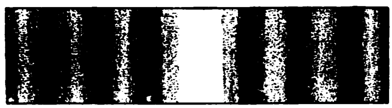

FIG. 166.

Polarization.

Experiment 159. — While looking through the plates of a pair of tourmaline tongs, turn one of the plates in its wire support. The intensity of the light transmitted will vary as the plate is turned. When little or no light is transmitted, the plates are said to be "crossed."

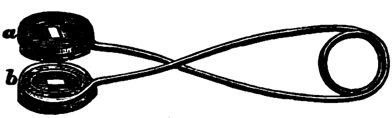

FIG. 167.

Experiment 160. — Write your name on a sheet of paper, and cover it with a crystal of Iceland spar. The lines will appear double, as shown in Fig. 168. Place the crystal over a dot on the paper, hold the eye directly over the dot, and slowly turn

FIG. 168.

the crystal around; one of the two images of the dot will revolve about the other image. Prick a pin-hole through a card, and hold the card against one side of the crystal, look through the crystal at the pin-hole, and rotate the crystal as before.

Experiment 161. — Look through one of the plates of the tourmaline tongs (Fig. 167) at the two images of the dot formed by the double refraction of the Iceland spar, as described in Experiment 160. One of the images will be much fainter than the other. Turn the tourmaline plate slowly around, and notice that one image grows fainter and the other brighter, the maximum brightness of one being simultaneous with the extinction of the other.

248. Polarization of Light. — Common white light embraces not only an indefinite number of wave-lengths, but also an indefinite number of modes of vibration. A transverse wave is capable of assuming a particular side or direction; a longitudinal wave is not. When a rope is shaken as described in Experiment 66, the vibrations of the wave thus produced lie in a vertical plane; when the hand is moved horizontally, the vibrations lie in a horizontal plane. In like manner, a single row of ether particles engaged in propagating a linear transverse wave may describe any one of a variety of paths, each being perpendicular to the line of propagation of the radiation.

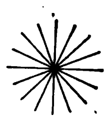

Fig. 169.

For example, each particle may vibrate in a straight line, parallel to the wave-front and indifferently in any plane about the line of propagation, as represented in Fig. 169. If all the ether particles in the row under consideration successively vibrate along lines lying in the same plane, the radiation is said to be plane-polarized, and the wave thus constituted is called a plane-polarized wave. *A change by which the transverse vibrations of luminous waves are limited to a single direction is called polarization of light.* This change may be produced in several ways.

(*a*) Light may be polarized by reflection from the surface of glass, water, and other non-metallic substances; by transmission through a series of transparent plates of glass placed in parallel position; and by double refraction, as in the case of Iceland spar, or of a plate cut in a certain way from a tourmaline crystal. A prism of Iceland spar prepared in such a way that one beam of polarized light is totally reflected and extinguished, while the other beam passes through as polarized light, is called a *Nicol prism*. Nicol prisms and tourmaline plates are largely used in experiments with polarized light.

(*b*) Light that has passed through a tourmaline plate, or been otherwise polarized, differs so much from ordinary light that it may be stopped by a similar plate, as was seen in Experiment 159. For the sake of simplicity, imagine the indifferently placed planes of vibration, as represented in Fig. 169, to be resolved into two that lie at right angles to each other, as shown in Fig. 170. Then the action of the first tourmaline plate may be compared to that of a vertical-bar grating that allows the vibrations in a vertical plane to pass, but absorbs the vibrations that lie in a horizontal plane. Evidently, the vibrations that pass one such grating, as T, will pass others similarly placed, but will be stopped by one that is crossed, as at T'. The part of the beam that lies between T and T' represents plane-polarized light.

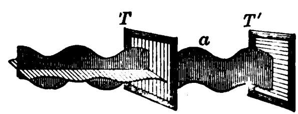

FIG. 170.

(*c*) An instrument for producing and testing polarized light is called a *polariscope*, one form of which is represented in the accompanying figure. Whatever its form, the instrument consists of two characteristic parts; one, used to produce polarization and called the *polarizer*, as the glass reflector at *a*, the other, used to test or to study the polarized light and called the *analyzer*, as the Nicol prism at *c*. Apparatus that serves for either of these purposes will serve for the other.

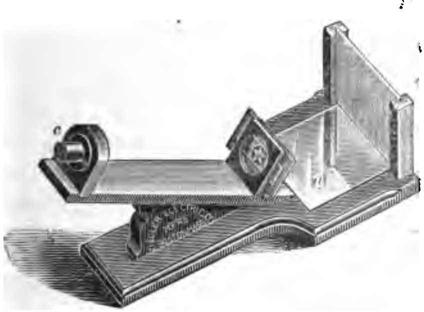

FIG. 171.

VII. A FEW OPTICAL INSTRUMENTS.

The Eye.

Experiment 162. — Close one eye and try to thread a needle. Bend a stout wire at a right angle, and try to pass one end of it through a ring held at arm's length, one eye being closed.

Experiment 163. — Prick a pin-hole in a card, hold it near the eye, and look through the pin-hole at a pin held at arm's length. As the pin is slowly moved toward the eye, the visual angle (§ 248, *c*) increases and the pin seems to grow larger.

249. The Human Eye, optically considered, is an arrangement for projecting inverted, real images upon a screen made of nerve filaments.

(*a*) The most essential parts of this instrument are contained in the eyeball, a nearly spherical body, about an inch in diameter, and capable of being turned considerably in its socket by the action of various muscles. The greater part of the outer coat is tough and opaque, and is called the white of the eye or the sclerotic coat, *S*; the front part of this coat is a hard, transparent structure called the cornea, *C*. The inner coat is the retina, *R*, an expansion of the optic nerve which enters the eyeball from behind. These coats form a camera filled with solid and liquid refractive media. The crystalline lens, *L*, a solid biconvex body, is suspended in this camera and directly in the axis of vision; it tends to flatten with age. With its capsule, it divides the eye into two compartments, and is chiefly instrumental in bringing the rays of light to a focus on the retina. The larger compartment of the eyeball is filled with a transparent jelly-like substance, *V*, the vitreous humor. The compartment between the cornea and the lens is filled with a more watery liquid, the aqueous humor, and is partly divided into anterior and posterior chambers by an annular curtain, *I*, called the iris.

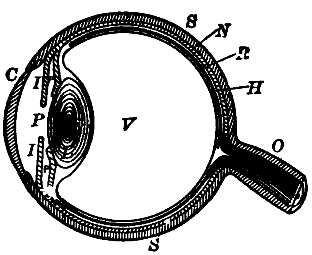

FIG. 172.

(*b*) Without our consciousness, the muscular action of the eye changes the curvature of the crystalline lens so that rays from near or distant objects may be focused on the retina. Instead of moving the screen, the refractive power of the lens is changed. This power of "accommodation," or automatic adjustment for distance, is limited. For instance, when a book is held close to the face, the rays from the letters are so divergent that the eye cannot focus them upon the retina. When the power of accommodation for distance is abnormally defective, the owner of the eye is said to be near-sighted, or far-sighted, or old-sighted. In the first case, the remedy is in concave glasses; in either of the other two cases, the remedy is in convex glasses. At the point where the optic nerve and its central artery enter the eyeball, the retina lacks the visual functions; this part of the retina is called the *blind spot.*

(*c*) The estimation of distances by the eye is a matter of judgment and is chiefly based upon experience. This experience relates to the amount of muscular effort exerted in adjusting the eye for distinct vision, and in turning the two eyes inward so that their axes meet at the object, thus forming the *optical angle* (see Experiment 162); to the comparison of the angle formed by lines drawn from the extremities of the object to either eye and called the *visual angle* with the visual angle subtended by objects of known size and distance; and to the observation of changes of color and brightness produced by the varying thickness of the air through which the object is viewed.

(*d*) The estimation of the size of distant objects is also a matter of judgment, based upon the known or supposed distance of the object. The ratio between the size of object and image equals the ratio between the distance of each from the lens, and the mind unconsciously bases its conclusions on this fact.

250. A Microscope *consists of a lens or a combination of lenses used to observe small objects*, often so minute as to be invisible to the unaided eye. Its magnifying power is the ratio between the length of the object and the length of its observed image.

(*a*) *The simple microscope* is generally a single convex lens. The object is placed between the lens and its principal focus. The lens increases the visual angle. The image is virtual, erect, and magnified.

(*b*) ***The compound microscope*** **consists essentially of two lenses or systems of lenses. One of these, *O*, called the *objective*, is of short focus. The object, *AB*, being placed slightly beyond the principal focus, a real image, *cd*, magnified and inverted is formed. The other lens, *E*, called the *eyepiece* or ocular, is so placed that the image, *cd*, lies between it and its focus. A magnified, virtual image of the real image, *cd*, is formed by the eyepiece and seen by the observer at *ab*. Eyepiece and objective are placed at opposite ends of sliding tubes, and so that they may be easily adjusted for distinct vision.**

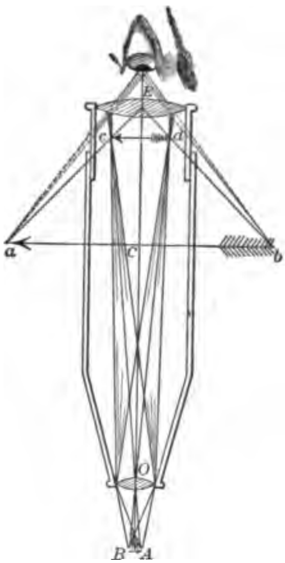

FIG. 173.

251. A Telescope ***is an instrument designed for the observation of distant objects***, and consists essentially of an objective for the formation of an image of the object and of an eyepiece for magnifying this image. The optical parts are generally set in a tube so arranged that the distance between the objective and the eyepiece may be adjusted for distinct vision. A telescope is refracting if its objective is a convex lens, and reflecting if its objective is a concave mirror. If it was designed for the observation of terrestrial objects, it is called a terrestrial telescope; if for the observation of celestial objects, it is called an astronomical telescope. Its magnifying power depends upon the ratio between the focal length of the objective and that of the eyepiece, and may be changed by changing one eyepiece for another.

(*a*) ***The astronomical refractor*** **consists essentially of a large convex lens objective of long focus, and a convex lens eyepiece of short focus. The real image formed by the objective is magnified by the eyepiece,**

as in the case of the compound microscope. The objective of a *reflecting* telescope is a concave mirror, technically called a *speculum.*

(*b*) *The spy-glass* or terrestrial telescope avoids the inversion of the image by the interposition of two double-convex lenses.

(*c*) *The Galilean telescope* has a double-concave eye-lens that intercepts the rays before they reach the focus of the objective. The rays

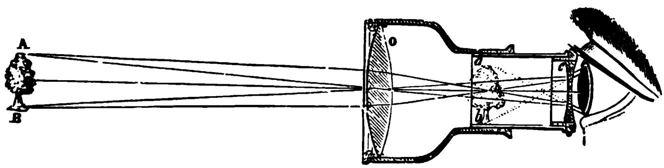

FIG. 174.

from *A*, converging after refraction by *O*, are rendered diverging by *C*. The image, *ab*, is erect and very near. Two Galilean telescopes placed side by side constitute an *opera-glass.*

Optical Projection.

Experiment 164. — Reflect a horizontal beam of sunlight into a darkened room. In its path, place a piece of smoked glass on which you have traced the representation of an arrow, *AB* (Fig. 175), or written your autograph. Be sure that every stroke of the pencil has cut through the lampblack and exposed the glass beneath. Place a convex lens beyond the pane of glass, as at *L*, so

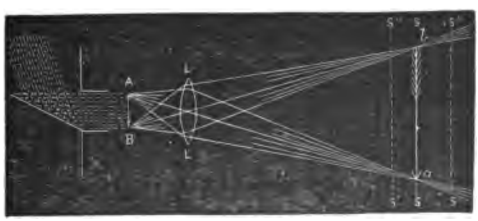

FIG. 175.

that rays that pass through the transparent tracings may be refracted by it, as shown in the figure. It is evident that an image will be formed at the foci of the lens. If a screen, *SS*, is held at the positions of these foci, *a* and *b*, the image will appear clearly cut and bright. If the screen is held nearer the lens or further from it, as at *S′* or *S″*, the picture will be blurred. The porte-lumière and slide-holding disk shown in Fig. 135 are very convenient for this purpose.

252. The Optical Lantern is an instrument for projecting on a screen magnified images of transparent photographs, paintings, drawings, etc.

(*a*) The light is placed at the common focus of a concave mirror, and of a convex lens, *L*, called the *condenser*. A powerful beam of light is thus thrown upon *ab*, the transparent object, technically termed a *slide*. A compound objective, *m*, is placed at a little more than its focal distance beyond the slide. A real, inverted, magnified image of the picture is thus projected upon the screen, *S*. The tube carrying *m* is adjustable, so that the foci may be made to fall upon the screen,

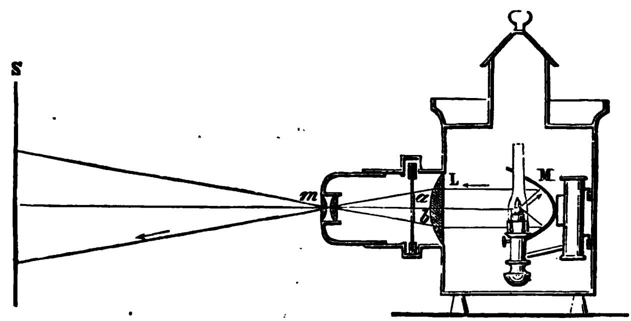

FIG. 176.

and thus render the image distinct. By inverting the slide, the image is seen right side up. An optical lantern is often called a *magic lantern*. Two matched lanterns placed so that their images coincide constitute a *stereopticon*.

EXERCISES.

1. In a good light, press together two pieces of clean plate-glass with a clamp at their centers, and explain the appearance of colors in the glass.

2. Spring a clothes-pin upon each of three corners of the glass plates used in Exercise 1, and support the plates by an iron clamp at the fourth corner. Let a beam of sunlight from the port-lumière fall upon the face of the plate so as to make the angle of incidence 45°. Receive the beam reflected from the plate upon a convex lens so that an image of the opening in the shutter will be projected on the screen.

Vary the pressure at the clamp, and explain the change of colors on the screen.

3. While a friend is looking intently at a distant object, look obliquely into his eye, holding a candle-flame on the other side of it. If the flame is properly held, three images of it will be seen; one erect and bright, reflected from the cornea; another erect and less bright, reflected from the anterior surface of the crystalline lens; and a third, inverted, reflected from the posterior surface of the lens. When the eye that is being studied changes its adjustment for the observation of an object held near it, the first image of the candle-flame is unchanged, while the second and third become smaller, the change being greater in the second than in the third.

4. Close the left eye and look steadily at the cross below, holding the book about a foot from the face. The dot is plainly visible as well

as the cross. Keep the eye fixed on the cross and move the book slowly toward the face. When the image of the dot falls on the "blind spot" of the eye, the dot disappears. Hold the book in this position for a moment and see if the changing convexity of the crystalline lens throws the image of the dot off the blind spot, making the dot again visible.

CHAPTER VI.

ELECTRICITY AND MAGNETISM.

(Ether Physics continued.)

I. GENERAL VIEW.

A. Static Electricity.

253. Electricity is the common cause of a large variety of phenomena, including apparent attractions and repulsions of matter, heating, luminous and magnetic effects, chemical decomposition, etc.

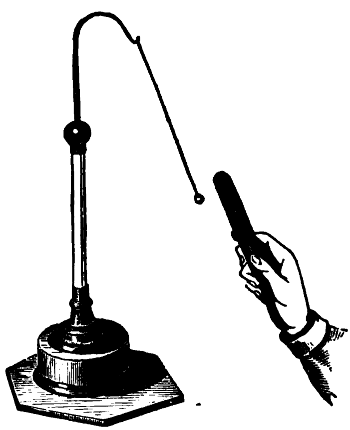

Fig. 177.

(*a*) The true nature of electricity is not yet well understood. Little more can be said at this point than that it is the agent upon which certain phenomena depend, and that it behaves like an incompressible fluid filling all space and entangled in the luminiferous ether.

Electrical Attraction.

Experiment 165. — Cut a number of pith-balls about 1 cm. in diameter. Whittle them nearly round, and finish by rolling them between the palms of the hands. Cover one of these balls with gold leaf, suspend it by a silk fiber, and call it an *electric pendulum*. Briskly rub a stout stick of sealing-wax with flannel, and bring it near the electric pendulum.

Notice the attraction. The sealing-wax and flannel should be dry and warm.

Experiment 166. — Rub a glass rod or tube (a long ignition-tube will answer) with a silk pad. The effect may be increased by smearing lard on one side of the pad and applying a coat of the amalgam that may be scraped from bits of a broken looking-glass. Small scraps of paper and other light bodies may be similarly attracted. The glass and silk should be dry and warm. Take like precaution in all experiments with static electricity.

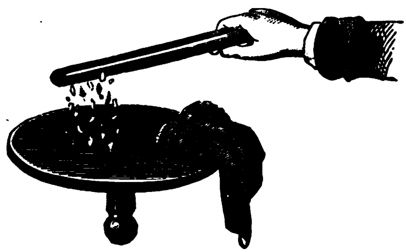

FIG. 178.

254. Electrification. — Bodies that are endowed with the power of attracting other bodies, as just illustrated, are said to be *electrified*. Any substance may be electrified by suitable means. The state or condition thus established is called *electrification*, and may be brought about in a variety of ways.

Electrical Conductivity.

Experiment 167. — Support a meter stick upon a glass tumbler. Bring an electrified glass rod to one end of the stick, and hold some small pieces of gold leaf or of paper a few centimeters under the other end of the stick. The gold leaf or the paper will be attracted and repelled by the stick as it previously was by the glass itself. The electrification passed along the stick from end to end.

255. Conductors and Insulators. — *Substances that easily permit the transference of electrification along them are said to be good conductors.* No substance is so good a conductor as not to offer some resistance to the transfer. Substances that offer very great resistances are called *insulators*, or *non-conductors*. A conductor supported by

an insulator is said to be *insulated*. An insulated body that is electrified is said to have a *charge*, or to be charged.

(*a*) In the following table, the substances named are arranged in the order of conductivity: —

Conductors.	Salt water.	Paper.	Glass.
Metals.	Linen.	Silk.	Sealing-wax.
Graphite.	Cotton.	India-rubber.	Vulcanite.
Acids.	Dry wood.	Porcelain.	*Insulators.*

(*b*) The fact that a conductor in the air may be insulated shows that air is a non-conductor. Dry air is a very good insulator, but moist air is a fairly good conductor. All experiments in static electricity are, therefore, more successfully performed in clear, cold weather when the atmosphere is dry.

(*c*) A medium intervening between two electrified bodies, i.e., a substance, solid, liquid, or gaseous, through or across which electric force is acting, is called a *dielectric*.

Kinds of Electrification.

Experiment 168. — Suspend several pith-balls by fine linen threads from an insulating support, and touch them with an electrified rod. The rod repels the balls, and the balls repel each other.

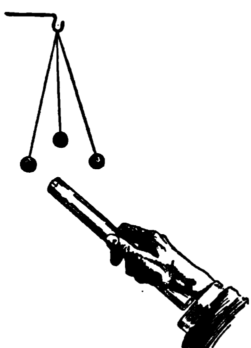

FIG. 179.

Experiment 169. — Bring an electrified glass rod near a pith-ball electroscope as before, and notice that, after contact, the ball is actively repelled. Similarly charge a second ball with an electrified rod of sealing-wax. Bring the two balls near each other, and notice their mutual attraction. Charge the two balls as before. Bring the glass rod near the ball that is repelled by the sealing-wax, and notice the attraction. Bring the sealing-wax near the ball that is repelled by the glass rod, and notice the attraction.

256. Opposite Electrifications. — Electrification may be manifested by repulsion as well as by attraction, and is

of two kinds, opposite in character. The electrification developed by rubbing glass with silk is called positive; that developed by rubbing sealing-wax with flannel is called negative. *Bodies similarly electrified repel each other; bodies oppositely electrified attract each other.*

(*a*) The statement that there are two kinds of electrification does not necessarily imply that there are two kinds of electricity. It is, however, very convenient to speak of one kind of electrification as caused by a charge of one kind of electricity, and the other kind of electrification as caused by a charge of an opposite kind of electricity.

(*b*) The electrification of the rubbed body is equal in amount to that of the body with which it is rubbed, but opposite to it in character.

257. Electrification by Conduction *is the process of charging a body by putting it in contact with an electrified body.* The charge thus produced is of the same kind as that of the communicating body.

258. The Electroscope *is an instrument for detecting and testing electrification.* The electric pendulum constitutes a simple and efficient electroscope.

FIG. 180.

(*a*) The gold-leaf electroscope represented in Fig. 180 is a common form of a more sensitive instrument. A metallic rod passes through the cork of a glass vessel, and terminates on the outside in a ball or a disk. The lower end of a rod carries two strips of gold leaf or of aluminium-foil that hang parallel and close together. When an electrified object is brought near the knob or into contact with it, the metal strips below become similarly charged and are, therefore, mutually repelled. The pupil can make one, using a glass fruit-jar or other bottle.

(b) A proof-plane (Fig. 181) may be made by cementing a cent or a disk of gilt paper to the end of a thin insulating handle, as a glass tube, and will be found very convenient in carrying a charge from an electrified body to an electroscope.

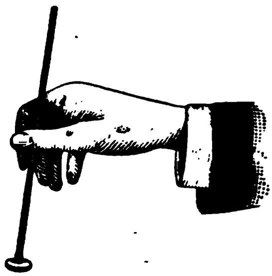

FIG. 181.

259. Electrical Units. — There are two systems of electrical units, one set being based upon the attraction or repulsion exerted between two quantities of electrification, and the other upon the force exerted between two magnet poles. Units of the former set are called *electrostatic;* those of the latter, *electromagnetic.* Distinctive names have not yet been adopted for the electrostatic units.

260. The Electrostatic Unit of Quantity *is the quantity of electrification that exerts through the air a force of one dyne on a similar quantity at a distance of one centimeter.* The force may be attractive or repulsive.

261. Law of Electric Action. — The force that is mutually exerted between two charges varies directly as the product of the charges, and inversely as the square of the distance between them.

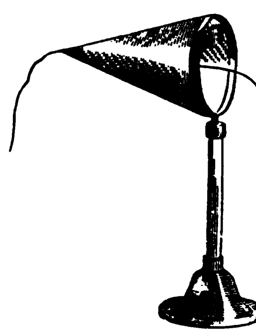

FIG. 182.

Distribution of the Charge.

Experiment 170. — Make a conical bag of linen, supported, as shown in Fig. 182, by an insulated metal hoop five or six inches in diameter. Electrify the bag. A long silk thread extending each way from the apex of the cone will enable you to turn the bag inside out without discharging it. Test

the inside and outside of the bag, using the proof-plane. Turn the bag and repeat the test. Whichever surface of the linen is external, no electrification can be found upon the inside of the bag.

Experiment 171. — Prick a pinhole at each end of an egg and blow out the contents of the shell. Paste tin-foil or Dutch-leaf smoothly over the entire surface of the empty shell. Pass a white silk thread through a light ring, and fasten its two ends with wax near the ends of the shell, so that the shell may be suspended with its greater diameter horizontal, or support it in this position on an egg-glass. Charge this insulated egg-shell conductor. With a proof-plane, carry a charge from the side of the conductor to the knob of the gold-leaf electroscope, and notice the degree of divergence of the leaves. In like manner, carry a charge from the smaller end of the conductor, and notice the greater divergence of the leaves.

Experiment 172. — Cement the end of a small glass tube to the middle of a pin, and hold the head of the pin against the knob of a charged gold-leaf electroscope. Observe the collapse of the leaves.

262. Distribution of the Charge. — *The charge lies wholly upon the outer surface.* The amount of electrification per unit of surface is called the *surface density*. Whenever a charge is communicated to a conductor, the electrification distributes itself over the surface of the conductor until it reaches a condition of equilibrium. It is greatest where the curvature is the greatest; on a sphere, the density is uniform; on an egg-shaped conductor, it is greatest at the smaller end.

(*a*) Since any charge is self-repulsive, there must be, at every point of the surface of a charged conductor, an outward pressure against the surrounding dielectric. When the density becomes about a hundred electrostatic units per square centimeter, the electrification cannot be retained upon the conductor, and sparks fly into the surrounding air. The discharge takes place most readily where the density is the greatest; i.e., where the curvature is the greatest, as at *a point*. Since the air in contact with such a point is similarly electrified, and, therefore, repelled, an air-current passes from the point, and the charge is dissipated by *convection*.

(*b*) Many pieces of apparatus for use with static electricity, made of wood and neatly covered with tin-foil put on with flour-paste, will prove as good conductors as if made wholly of metal.

263. Process of Electrification. — *When two dissimilar substances are brought into contact and then separated, they are equally and oppositely electrified.*

(*a*) If the substances are poor conductors, they must be rubbed together. If the substances are good conductors, the opposite and equal electrifications flow to the point last in contact, and pass by conduction from one to the other; the resultant is zero.

264. Electrical Field and Lines of Force. — *The space surrounding an electrified body and through which the electrical force acts is called an electrical field of force.* We may imagine lines drawn in this field, each indicating the direction in which a unit of electrification would move if placed in the field.

(*a*) To "map" an electrical field and to show the relative intensity of different parts of it, it has been agreed that one line shall be drawn through each square centimeter of surface for each dyne of force exerted in the field. Try to imagine two electrified bodies as immersed in an electrical field of force, and connected by elastic lines of force that tend to shorten and that are self-repellent.

265. Potential. — In a general way, it may be said that *potential represents degree of electrification*, or that it is the relative condition of a conductor that determines the direction of a transfer of electrification to it or from it.

(*a*) *An electrostatic unit difference of potential exists between two points when an erg of work is involved in moving unit charge from one point to the other.*

(*b*) As the sea-level is taken as the zero from which altitudes are measured, so the surface of the earth is taken as the zero of electric potential. As water tends to flow from higher to lower levels, and as heat tends to flow from places of higher to places of lower temperature, so electrification tends to flow from places of higher to places of

lower potential until an equalization is reached. In the latter case, the flow is called a *current of electricity*.

(*c*) Surfaces throughout which the potential is everywhere the same are called *equipotential surfaces*. If any two points in such a surface were to be joined by a conductor, no flow of electrification would take place.

266. Electromotive Force.—If two conductors at different potentials are connected by a wire, a transfer of electrification will take place until the difference of potential disappears. *Whatever its nature, the agency that tends to produce such a transfer is called electromotive force.*

Electrostatic Induction.

Experiment 173.—Electrify a glass rod by rubbing it with silk, and bring it near the electroscope but without making contact. The leaves diverge. When the rod is removed, the leaves fall together. Repeat the experiment, holding a glass plate between the rod and the electroscope.

Experiment 174.—Bring a metallic sphere positively charged near an insulated cylindrical conductor with hemispherical ends and provided with pith-ball and linen-thread electroscopes as shown in Fig. 183. The divergence of the pith-balls shows electrification at the ends but not at the middle of the conductor. With the proof-plane and gold-leaf electroscope, examine the condition of the conductor at the points *A*, *B*, and *m*, and compare your results with the representations in the figure. Remove the sphere from the vicinity of the conductor, or discharge it by touching it with the hand. All signs of electrification on the conductor disappear, showing that the charges at *A* and *B* were opposite and equal.

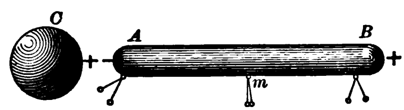

FIG. 183.

NOTE.—Instead of the sphere, *C*, you may use the egg-shell conductor used in Experiment 171. The cylindrical conductor may be replaced by two such conductors that are in contact, end to end. See § 262 (*b*).

Experiment 175. — Electrify the insulated conductor, *AB*, as in Experiment 174. Touch it with the finger, thus connecting it with the earth and making it of indefinite length; its positive electrification is so diffused as to be insensible. Remove first the finger and then the electrified sphere. The negative electrification, being no longer held at *A* by the attraction of the positive electrification at *C*, diffuses itself over the cylinder, and the balls at each end of the cylinder diverge, all being charged negatively.

Experiment 176: — From a horizontal rod, suspend two egg-shell conductors by silk threads as described in Experiment 171. Be sure that the shells are in contact end to end. Bring an electrified glass rod near one of them, and slide the loop of the other along the supporting rod until the shells are about 10 cm. apart. Then hold the electrified rod between the shells. It will attract one and repel the other, showing that they are oppositely electrified.

267. Electrification by Induction. — Whenever an electrified body is brought into the vicinity of an unelectrified conductor, the unelectrified conductor becomes electrified. A dissimilar electrification appears on the side nearer the electrifying conductor, and similar electrification upon the further side. *Electrification produced in this way, by the influence of an electrified body and without contact with it, is called electrification by induction.* An induced charge is opposite in kind to the charge of the inducing body.

(*a*) The amount of inductive effect that takes place across an intervening medium depends, in a considerable degree, upon the nature of that medium.

268. The Capacity *of a conductor is the amount of electrification required to raise its potential from zero to unity, i.e., the ratio of its charge to its potential.*

(*a*) The unit of capacity is the capacity of a conductor that requires unit quantity to produce unit difference of potential; it is called a *farad;* one-millionth of a farad is called a *microfarad.*

Condensers.

Experiment 177. — Spread a sheet of tin-foil upon a pane of glass supported on a tumbler. Charge the tin-foil by repeated sparks from the electrophorus (§ 313) until it will receive no more. Count the number of sparks that the tin-foil will receive.

Experiment 178. — Lay a sheet of tin-foil upon the table so that it will be in electrical connection with the earth. Over it place the glass and foil used in Experiment 177. Charge the upper sheet as before, and notice that it will receive a much greater number of sparks. Touch the lower sheet of tin-foil with a finger of one hand, and the upper sheet with a finger of the other hand, thus discharging the apparatus. A pricking sensation will be caused by the discharge.

269. A Condenser is a device for increasing the electrical density without increasing the potential, i.e., for accumulating a large charge with a small electromotive force. In its simplest form *it consists of a pair of conductors slightly separated by a dielectric.* If one of these conductors is connected to earth, it requires a much larger quantity of electrification to raise the potential of the other from zero to unity, i.e., the capacity of the other is greatly increased. The smaller the distance between the conducting surfaces, the greater the capacity of the condenser.

(*a*) The nature of the dielectric has a great effect on the capacity of the condenser. For instance, changing the dielectric from air to ebonite more than doubles the capacity of the condenser. Condensers of the flat type (Fig. 184), consisting of tin-foil conductors separated by thin, flat dielectric sheets (usually of mica), are much used. To obtain large area, and hence great capacity, they are arranged alternately in two series.

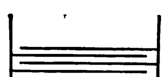

FIG. 184.

(*b*) The most common and, for many purposes, the most convenient form of condenser is the Leyden jar. This consists of a glass jar coated within and without for about two-thirds its height with tin-foil, and a metallic rod that communicates with the inner coat, and terminates above in a knob or a disk. The jar may be a smooth, thin tumbler of good glass, and the tin-foil may be put on with flour-paste.

The knob may be carried at the upper end of a wire, the lower end of which is wound into a flat coil that rests on the foil at the bottom of the tumbler. The coil may be fastened in position with hot sealing-wax. Evidently, it may be considered as a flat condenser rolled into cylindrical form. The phenomenon of electrification pertains to the dielectric and not to the conducting plates. The metallic coats simply provide the means for the prompt discharge of the superficial layers of the molecules of the dielectric. A number of Leyden jars having their coats connected constitutes an *electric battery.*

FIG. 185.

(*c*) The jar may be charged by holding it in the hand as shown in Fig. 185, or otherwise placing the outer coat in electrical connection with the earth, and bringing the knob into contact with a charged body. If the outer coat is insulated so that the repelled electrification cannot pass to the earth, the jar cannot be very highly charged. To discharge the jar, pass a stout wire through a piece of rubber tubing and bend it into a V shape, or, in some other way, provide the wire with an insulating handle. Bring one end of the wire into contact with the outer coat, and then bring the other end into contact with the knob. It is well to provide the wire "discharger" with metal balls at the ends.

270. Nature of Electricity. — According to the general belief of physicists, *electricity is a form of matter rather than a form of energy.* A full discussion of the nature of electricity is beyond the province of this book, but it is safe for us to say that *electricity is that which is transferred from one body to another in the process of electrifying them.*

271. Theory of Electrification. — When electricity is transferred from one body to another and the bodies are separated (see § 263) against their mutual attraction, the intervening medium is thrown into a state of strain indicated by the lines of force. *This state of strain in the dielectric constitutes electrification.* Whatever the real nature

of electricity, ***electrification results from work done, and is a form of potential energy.***

EXERCISES.

1. How can you show that there are two opposite kinds of electrification?

2. How would you test the kind of electrification of an electrified body?

3. Why is it desirable that a glass rod used for electrification be warmer than the atmosphere of the room where it is used?

4. (*a*) Having a metal globe positively electrified, how could you with it negatively electrify a dozen globes of equal size without affecting the charge of the first? (*b*) How could you charge positively one of the dozen without affecting the charge of the first?

5. When a pin or needle is held with its point near the knob of a charged gold-leaf electroscope, the leaves quickly collapse. Explain.

6. A Leyden jar standing on a plate of glass cannot be highly charged. Why?

7. Will you receive a greater shock by touching the knob of a charged Leyden jar when it is held in the hand or when it is standing on a sheet of glass? Explain.

8. Quickly pass a rubber comb through the hair and determine whether the electrification of the comb is positive or negative.

9. Show that an electric charge is self-repulsive by blowing a soap-bubble on a metal pipe and then electrifying it. Compare the change in the size of the bubble with that noticed in Experiment 17.

10. Twist some tissue paper into a loose roll about six inches long. Stick a pin through the middle of the roll into a vertical support. Present an electrified rod to one end of the roll, and thus cause the roll to turn about the pin as a horizontal axis. Give this piece of apparatus a scientific name.

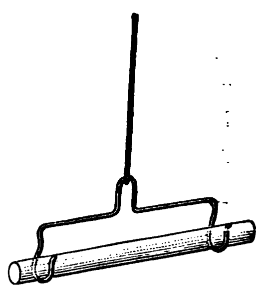

FIG. 186.

11. Prepare two wire stirrups, A and B, like that shown in Fig. 186, and suspend them by silk threads. Electrify two glass rods by rubbing them with silk, and place them in the stirrups. Bring A near B. Notice the repulsion. Repeat the experiment with two sticks of

sealing-wax that have been electrified by rubbing with flannel. Notice the repulsion. Place an electrified glass rod in A, and an electrified stick of sealing-wax in B. Notice the attraction. Give the law illustrated by these experiments.

12. Place a gold-leaf electroscope inside an insulated tin pail and electrify the pail. Describe and explain the indications given by the electroscope.

13. Insulate a tin pail, and run a fine wire from its edge to the knob of an electroscope. Suspend a metal ball by a silk thread, electrify it, and lower it into the pail without contact. Notice and account for the divergence of the leaves of the electroscope. Touch the pail with a finger. Notice and account for the collapse of the leaves. Remove the finger and withdraw the ball. Notice and account for the divergence of the leaves. If the ball is negatively charged, what is the final charge of the electroscope?

B. Current Electricity.

Preliminary.

Experiment 179. — Partly fill a tumbler with a solution made by slowly pouring one part of sulphuric acid into ten parts of water. Place a strip of zinc, 2 × 10 cm., in the tumbler of dilute acid, and *notice the bubbles that rise.* Apply a flame to them as they reach the surface of the liquid, and notice that they burn with slight puffs. Hydrogen is evolved by the chemical action between the zinc and the acid.

Experiment 180. — Take the metal strip from the tumbler of acid and, while it is yet wet, rub thereon a few drops of mercury, thus *amalgamating the zinc.* The amalgamated surface will have the appearance of polished silver. Replace the zinc in the acid, and notice that no bubbles are given off. Place a copper strip, 2 × 10 cm., in the solution, being careful that it does not touch the zinc. No bubbles appear on either the copper or the zinc. Bring the strips together at their upper ends as shown in Fig. 187. Bubbles now arise from the copper. Connect the metals above the liquid by a piece of copper wire, about No. 18. The same results are observed.

Fig. 187.

NOTE. — Always make such connections secure, metal to metal, and with large area of contact. Each metal strip may be bent at the top so as to clasp the edge of the tumbler, leaving the part on the inside long enough to reach very nearly to the bottom.

Experiment 181. — Solder a wire 50 cm. long to each of the metal strips used in Experiment 180. Place the strips in the acid, and bring the free ends of the wires into contact with the tongue, one above and one below it, being sure that there is no acid on the wires. A bitter, biting taste is felt. Make sure that this taste disappears when either strip is removed from the solution, when either wire is disconnected from the tongue, or when the circuit is broken at any point. Notice that the hydrogen bubbles cling tenaciously to the copper, and that, by this "polarization of the cell," its electrical power is much diminished.

272. Suspicion. — It seems as though a metallic contact is necessary to bring about this phenomenon of bubbles on the copper. We have a complete circuit of materials, copper strip, wire, zinc strip, and acid. Perhaps we do not see all that is taking place in the system.

Voltaic Cell and Electric Current.

Experiment 182. — Put the cover of a tin spice-box into a fire and thoroughly melt the tin coating from the iron plate. Use the cover thus prepared as a mold for casting a zinc plate 6 mm. thick. While the zinc is still liquid, embed in it the bent end of a wire about 30 or 40 cm. long. When the zinc has cooled, remove it from the mold and straighten the wire, which should project from the edge of the plate as shown in Fig. 188. Smooth the rough edges of the zinc with a file, and amalgamate it.

FIG. 188.

Invert a common tumbler on a square board of soft pine, about 1.5 cm. thick, and large enough to serve as a cover for it. Run a pencil around the edge of the tumbler and draw the diagonals of the inscribed and circumscribed squares, as shown in Fig. 189. Bore holes as shown at *a*, *b*, *c*, and *d* just large enough to admit an electric (arc) light carbon. Cut four such carbons to lengths that are equal and less than the depth of the tumbler. If the carbons are copper-coated, dissolve the copper with nitric acid from all of the rod except

1.5 cm. at the upper end. Insert one end of each carbon into one of the holes, and connect the four carbons by a copper wire as shown in Fig. 190. Pass the wire of the zinc plate through a small hole at the middle of the board, so that the plate may be suspended in the tum-

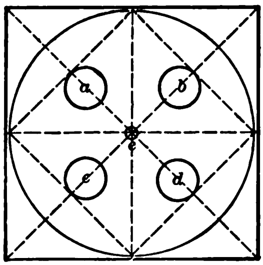

FIG. 189.

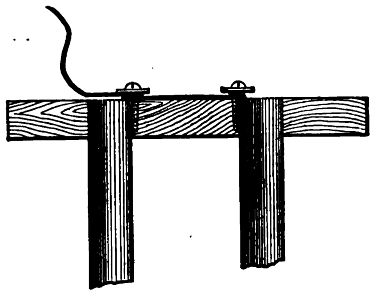

FIG. 190.

bler, as shown in Fig. 191. Wedge the wire in place. Be careful that this wire does not touch the wire from the carbons on the top of the cover. Insulated wire may be used for supporting the zinc, the end that is to be embedded in the zinc being scraped bare before the casting.

Prepare a solution as follows: slowly pour 167 cu. cm. of sulphuric acid into 500 cu. cm. of water, and let the mixture cool. Dissolve 115 g. of potassium dichromate (bichromate of potash) in 335 cu. cm. of boiling water, and pour the hot solution into the dilute acid. When this liquid is cool, fill the tumbler about two-thirds full with it, and place the carbons and zinc therein. Adjust the height of the plate as shown in Fig. 191, and be sure that the zinc does not touch any of the carbons. The zinc and carbon should be kept in the fluid no longer than is necessary. It is well to provide a second tumbler in which to drain them. Each pupil should make at least one of these cells; he will find three or four of them very useful.

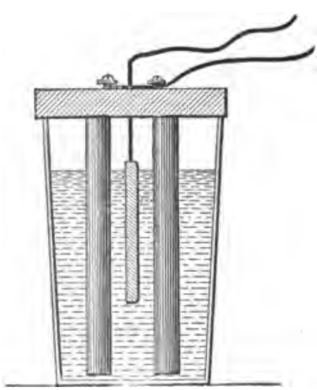

FIG. 191.

Hold the two wires of this or of some other good cell, end to end, over a compass-needle and parallel to its length, as shown in Fig. 192. No change appears. Bring the two ends of the wire into contact, and

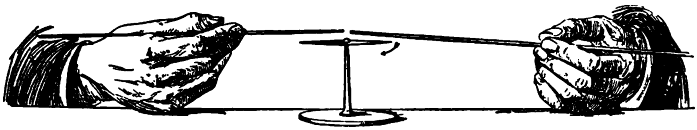

FIG. 192.

thus close the circuit. The needle instantly flies around as though it was trying to place itself at right angles to the wire. Break the circuit, and the needle swings back to its north and south position. Twist the wires together, and bend the conductor into a loop so that the current passes above the needle in one direction and beneath the needle in the other direction. The deflection of the needle will be greater than before. If the wire is formed into a loop that makes several turns about the needle, the deflection will be still greater. Notice the direction in which the north-seeking end of the needle turns. Reverse the cell connections, and notice that the needle deflects in the opposite direction. See Experiment 192.

273. Certainty. — We are now sure that something unusual is going on in the wire. *This something is called a current of electricity. The containing vessel, the plates, and the exciting liquid constitute a voltaic cell.*

FIG. 193.

(*a*) There is a difference of potential between the plates, and the chemical action between the liquid and one or both of the plates, or some other cause, tends to maintain that difference.

274. Direction of Current. — We cannot conceive a current without direction. The actual direction of current-flow is not known, but, for the sake of convenience and uniformity, electricians assume that the current flows from the carbon

through the wire to the zinc, and from the zinc through the liquid to the carbon.

275. Plates, Poles, etc. — The entire path traversed by the current, including liquids as well as solids, is called the *circuit.* The plate that is the more vigorously acted upon by the liquid is called the *positive plate;* the other is called the *negative plate.* The free end of the wire attached to the negative plate is called the *positive pole* or electrode; that of the wire attached to the positive plate is called the *negative pole* or electrode. In any part of an electric circuit, a point from which the current flows is called positive (+) and a point toward which the current flows is called negative (−). When the two electrodes are joined, *the circuit is closed;* when they are separated, *the circuit is broken.*

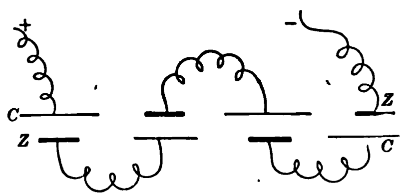

FIG. 194.

(*a*) When several cells are connected so that the positive plate of one is joined to the negative plate of the next, as zinc to carbon, and so on, as shown in Fig. 194, they are said to be grouped or joined *in series.* When all of the positive plates are connected on one side, and all of the negative plates are connected on the other side, as shown in Fig. 195, the cells are said to be joined *in parallel,* or *in multiple arc.* A number of cells joined in either way is called a *voltaic battery.*

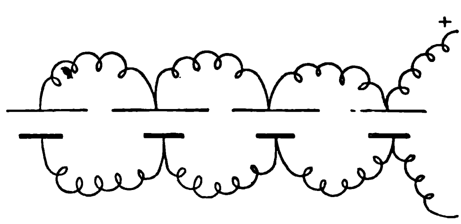

FIG. 195.

NOTE. — The representation of the zinc and carbon plates, as at Z and C in Fig. 194, is the conventional way of representing a voltaic cell.

Resistance.

Experiment 183. — Provide a flat piece of soft pine wood about 10 cm. square and 3 cm. thick, and wind on evenly one layer of No. 16 cotton-covered or insulated copper wire covering the greater part of the block. Secure the two ends of the wire by double-pointed tacks. Place a small pocket compass upon the block thus wound, and turn the block until the coils of the wire are parallel to the needle when the circuit is open. Pass a current through the coil, quickly notice how much the needle has been deflected, and break the circuit. The instrument you have made is called a *galvanoscope.*

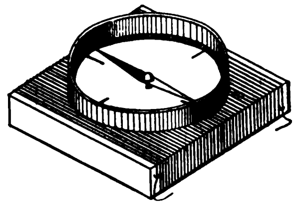

FIG. 196.

Experiment 184. — Interpose 20 feet of No. 30 (or finer) iron wire in the circuit of a voltaic cell. Connect it so that the current will flow from the carbon through the galvanoscope, through the iron

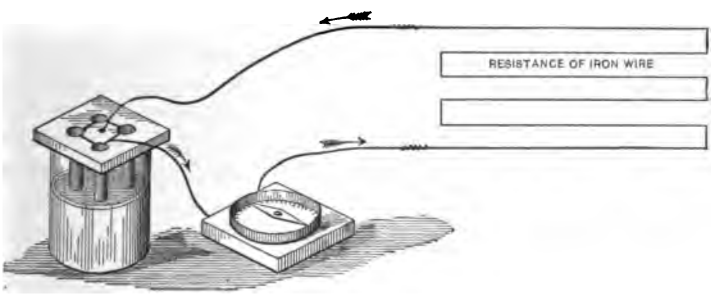

FIG. 197.

wire, and back to the cell. In other words, connect the wire and galvanoscope in series. *The deflection will be less than before.* Keep the current on just long enough to read the galvanoscope.

276. Resistance. — *The property of a conductor, by virtue of which the passage of an electric current through it is diminished, and part of the electric energy is transformed into heat, is called resistance.* Nothing is known of its nature, but it pertains to all substances.

(*a*) Any material device, such as a coil of wire, introduced into an electric circuit on account of the resistance that it offers to the passage of the current, is called a resistance.

(*b*) *The ohm is the practical unit of resistance.* It is the resistance of a column of pure mercury one square millimeter in cross-section, and 106.3 centimeters long, and at a temperature of 0°. A thousand feet of No. 10 copper wire, or 9.3 feet of No. 30 copper wire, has a resistance of very nearly an ohm, — an important "rough and ready" standard. A million ohms is called a *megohm;* one-millionth of an ohm is called a *microhm.*

Laws of Resistance.

Experiment 185. — Provide 20 feet of No. 30 iron wire, 20 feet of No. 30 copper wire, 60 feet of No. 30 iron wire, and 20 feet of No. 20 iron wire. Repeat Experiment 184 with each of these wires, in each case noting the deflection of the galvanoscope, *G.*

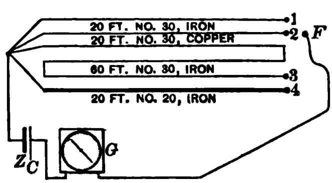

FIG. 198.

Each wire may be coiled on a board, care being taken that adjacent coils do not touch. Coiled or uncoiled, the wires may be connected as in Fig. 198, and the free end of *F* touched at 1, 2, 3, and 4 successively. Give the cell a moment's rest between successive contacts.

277. Laws of Resistance: —

(1) *Other things being equal, the resistance of a conductor is directly proportional to its length.*

(2) *Other things being equal, the resistance of a conductor is inversely proportional to its area of cross-section.*

(3) *Other things being equal, the resistance of a wire depends upon the material of which it is made.*

(*a*) The resistance of metals is raised, and the resistance of carbon is lowered by heating. At a given temperature, resistance is directly proportional to a constant that is different for different substances. This constant, *K*, is called the *specific resistance* or the *resistivity* of

the material. Resistivity is the reciprocal of *conductivity.* Tables of resistances, etc., are given in the appendix.

NOTE. — In many respects, it is convenient to compare the flow of electrification through a wire to the flow of water through a horizontal pipe. Such a comparison yields the following analogues: —

Functions.	*Hydraulic Units.*	*Electromagnetic Units.*
Pressure.	Head in feet.	Volt.
Quantity.	Pound.	Coulomb.
Rate of flow.	Pounds per second.	Coulombs per second, or ampere.
Resistance.	No definite unit.	Ohm.
Work.	Foot-pound.	Joule.
Rate of work.	Foot-pounds per second, or horse-power.	Volt-ampere, or watt.

278. The Volt. — Hydraulic pressure might be called water-moving force; electrical pressure is called electromotive force (E.M.F.). *The practical unit of electromotive force is called the volt;* it is almost the same as the electrical pressure of a cell consisting of a copper and a zinc plate immersed in a solution of zinc sulphate.

(*a*) Although difference of potential is measured in volts, it is a different thing from electromotive force. The electromotive force of a circuit is the total electrical pressure existing therein, while the difference of potential is merely the difference of electrical pressure between two points on the circuit. A generator of electricity for arc lights may have an electromotive force of 3,000 volts, while the difference of potential between the terminals of an arc lamp in the circuit is only 45 volts.

279. The Ampere. — *The unit of rate of flow, or current strength, is the ampere,* which may be defined as the current flowing per second through a wire having a resistance of one ohm, and between the ends of which a potential difference of one volt is maintained. A thousandth of an ampere is a *milliampere.*

280. Ohm's Law. — Representing current strength by C, voltage, i.e., electromotive force, by E, and resistance by R, the numerical relations of these functions of an electrical current are expressed by the formula,

$$C = \frac{E}{R}, \text{ or } E = C \times R, \text{ or } R = \frac{E}{C}.$$

Any two of these being known, the third may be found.

(*a*) Applied to an electric generator (as a dynamo or a voltaic cell), we may represent the resistance of the external circuit by R and the internal resistance of the generator itself by r. Then

$$C = \frac{E}{r + R}.$$

Thus, if the E.M.F. of a chromic acid cell is 2 volts, the internal resistance of the cell is 1.5 ohms, and the wire resistance is 0.5 ohms,

$$C = \frac{2}{1.5 + 0.5} = 1.$$

The current strength will be 1 ampere.

281. The Coulomb is the quantity of electrification carried past any point by a 1-ampere current in one second. The unit is rather large for practical purposes, and is but little used.

282. The Joule *is the electrical unit of work*, and represents the energy of one coulomb delivered under a pressure of one volt.

Joules = *volts* × *coulombs*.

283. The Watt *is the unit of electrical activity or power*, and represents the rate of working in a circuit when the electromotive force is one volt and the current is one ampere. One horse-power equals 746 watts.

Watts = *volts* × *amperes*.

(*a*) Representing algebraically the definition of the watt, we have

$$W = E \times C. \tag{1}$$

Substituting, in this equation, the value of E given in § 280, we have

$$W = R \times C^2. \tag{2}$$

Substituting, in the same equation, the value of C given in § 280, we have

$$W = \frac{E^2}{R}. \tag{3}$$

Heating Conductors.

Experiment 186. — Join equal lengths of iron wires of different sizes end to end, and pass a gradually increasing current through them. The smallest wire will be most heated.

Experiment 187. — Join, end to end, equal lengths of iron and copper wires of the same size, and increase the current that passes through them until the iron wire is red-hot. Ascertain the thermal condition of the copper wire.

284. Distribution of Heat. — *The heat developed in any part of an electric circuit is proportional to the resistance of that part of the circuit, or to the fall of potential through that part of the circuit.*

285. Shunts. — When part of a circuit consists of two branches, each branch is said to be a shunt to the other.

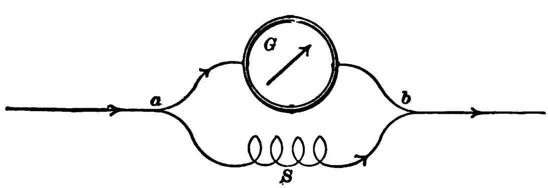

Fig. 199.

The current flowing through such a circuit will divide, part of it going one way, and the other part the other way.

(*a*) The current that flows through the branches will be inversely proportional to the respective resistances of the branches. Suppose that the branch that carries the galvanometer, G, has a resistance of 900 ohms, and that the branch that carries the coil, S, has a resistance of 100 ohms. Then 0.9 of the current will flow through S, and 0.1 through G.

(*b*) The introduction of a shunt lessens the resistance of the circuit. In a case like that above specified, the resistance of the part between a and b will be less than that of either of its branches, thus:—

$$R = \frac{900 \times 100}{900 + 100} = 90, \text{ the number of ohms.}$$

EXERCISES.

1. What is the resistance of a No. 10 copper wire, 1,000 feet long? (Consult the table in the appendix.)

2. What is the resistance of 750 feet of iron wire, No. 8?

3. What is the resistance of 6,050 feet of copper wire, No. 25?

4. A copper wire is carrying a 5-ampere current. The resistance of this wire is 2 ohms.

(*a*) How many volts are necessary to force the current through the wire?

Solution:—$E = C \times R = 5 \times 2 = 10$, the number of volts.

(*b*) How much energy is consumed in the wire?

Solution:—$W = E \times C = 10 \times 5 = 50$, the number of watts; or
$W = R \times C^2 = 2 \times 25 = 50$, the number of watts.

5. An incandescence lamp is connected with an electric generator (dynamo) 300 feet away by a No. 18 copper wire that is carrying a 1-ampere current. A fine coil galvanoscope would show differences in potential between the ends of the two wires running to the lamp, and between the two terminals of the lamp itself. What is the loss voltage due to the line?

Solution:—The table of resistances given in the appendix shows that the resistance of the 600 feet of wire is 3.83466 ohms.

$$E = C \times R = 1 \times 3.83466 = 3.83466, \text{ the number of volts.}$$

If the lamp took 1 ampere at 100 volts, the line loss would be nearly 3.8 per cent.

6. What would be the proper size of copper wire to supply a group of lamps 400 feet away, and taking 15 amperes, so that the line loss shall be 2 volts?

Solution: — The resistance of the line would be,

$$R = \frac{E}{C} = \frac{2}{15} = 0.1333, \text{ the number of ohms.}$$

Its resistance in ohms per foot must be $(0.1333 \div 800 =)$ 0.0001666, and the resistance per 1,000 feet, 0.1666 ohms. From the table, we find that No. 2 is the nearest size of wire.

7. The wire loss of an electric motor is 156 watts. If the resistance of the motor is 2 ohms, what current flows?

Solution: —

$$W = R \times C^2; \; C = \sqrt{\frac{156}{2}} = 8.83, \text{ the number of amperes.}$$

8. How many foot-pounds per minute equal a watt? *Ans.* 44.236.

9. How many horse-power will be absorbed by a circuit of arc lamps, taking 9.6 amperes at 2,900 volts pressure?

Ans. 37.32 H.P., nearly.

10. A group of incandescence lamps absorbs 21 amperes. The line loss is limited to 1.5 volts.

(*a*) What is the resistance of the line? *Ans.* 0.07143 ohm.

(*b*) How many watts are lost? *Ans.* 31.5 watts.

11. What mechanical horse-power is necessary for 50 incandescence lamps, each taking 0.5 ampere at 110 volts, allowing 10 per cent loss for transformation from mechanical into electrical energy?

Ans. 4.09 H.P.

12. What energy is absorbed by a coil of wire of 23 ohms resistance, through which a current of 3.5 amperes is flowing?

Ans. 281.75 watts.

13. Wind four or five layers of No. 20 insulated copper wire upon the edge of a board 25 cm. square. Slip the wire from the board and tie together the several turns of the wire at the corners of the rectangle. Bend one end of the wire into a hook and solder it to the middle of the pointed half of a sewing-needle as shown at *m* in Fig. 200. Straighten the other end at a right angle, as shown at *n*. Bend a narrow strip of brass at a right angle, and in one arm make an indentation that will hold a globule of mercury. Support the brass L with the indented arm horizontal, and from it hang the wire rectangle. A globule of

mercury insures a good condition at *m*, and the straightened part of the wire dips into a cup of mercury at *n*. Adjust the form of the supporting hook so that two sides of the rectangle are horizontal, and place the face of the rectangle in a north and south plane. Pass the current of a battery of 3 cells through the apparatus, and notice that the rectangle turns into an east and west plane. Reverse the current and notice the effect. Make a record of this motion of the wire rectangle, and reserve it for future study.

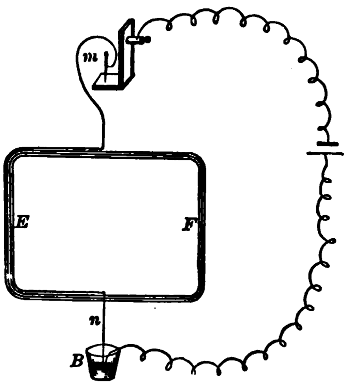

FIG. 200.

14. Wind four or five layers of No. 20 insulated copper wire upon the edge of a board 10 × 20 cm. Slip the wire from the board, and tie as directed in Exercise 13. Place this coil in the circuit between the battery and the mercury cup at *n*, Fig. 200. Call the larger wire rectangle *A*, and the smaller one *B*. Hold *B* with one of its 20 cm. sides vertical and near one side of *A*. Record the effect as manifested by the motion of *A*, when the current flows upward through the adjacent sides of the two rectangles; when the current flows downward through both; and when it flows upward in one and downward in the other. Formulate a general expression of the action of parallel currents upon each other. (*a*) When they flow in the same direction. (*b*) When they flow in opposite directions. The consideration of the interaction between currents as herein illustrated constitutes the subject-matter of *electrodynamics*.

15. Wind some No. 16 insulated copper wire into a close spiral about 4 cm. in diameter and 15 cm. long. Bend its ends as indicated in Fig. 201. Put it into the circuit of the battery as directed for the rectangle of Exercise 13 and hold a bar magnet near one of its ends. Trace the current through the *solenoid*.

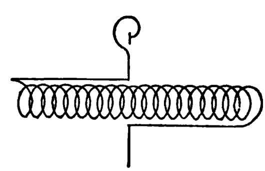

FIG. 201.

16. Pass two stout copper wires separately through a cork about

2 cm. in diameter. About 2 cm. from the smaller end of the cork, connect the copper wires with a short piece of very fine iron wire. Wrap the edge of a strip of paper about 5 cm. wide around the cork so as to make a paper cup with the iron wire inside. Fill the cup with fine gunpowder, and close the other end with a cork or a paper cap. Place this torpedo at a safe distance, connect it by stout copper wires to a voltaic battery, and send through the wires a current that will heat the iron wire and explode the torpedo. State some industrial application of electricity that is illustrated by this exercise. Cut the leading wires at three or four points and join them with short pieces of fine iron wire. Tie the fuse of a fire-cracker around each piece of iron wire, and send a current that shall ignite all of the fuses.

C. Magnetism.

Artificial Magnets.

Experiment 188. — Wrap a piece of writing paper around a large iron nail, leaving the ends of the nail bare. Wind fifteen or twenty turns of stout insulated copper wire around this paper wrapper. Put this spiral into the circuit of a voltaic cell, and dip the nail into iron filings. Some of the filings will cling to the ends of the nail in a remarkable manner. Upon breaking the circuit, the nail instantly loses its newly acquired power, and drops the iron filings.

Experiment 189. — Draw a sewing-needle four or five times from eye to point across one end of the nail used in Experiment 188, while the current is flowing through the wire wound upon it. Dip the needle into iron filings. Some of the filings will cling to each end of the needle.

Experiment 190. — Break the tangs from a few flat, worn-out files. Smooth the ends and sides of the files on a grind-stone. Get some good-natured dynamo tender to magnetize these hard-steel bars, and three or four stout knitting-needles. You can magnetize the needles yourself by winding upon them successively, evenly, and from end to end, a layer of insulated No. 20 wire, and sending a current from a voltaic battery through the wire. Freely suspend these *permanent magnets* at a considerable distance from each other and so that each can turn in a horizontal plane. The knitting-needles may be thrust through two corners of triangular pieces of paper to the third corner of which the end of a horse-hair is fastened by wax. The heavier

magnets may be placed in stout paper stirrups similarly supported, or they may be floated upon water, as shown in Fig. 202. ***The magnets will come to rest in a north and south line.*** **Mark the north-seeking end of each magnet so that it may be distinguished from the other.**

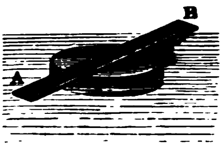

FIG. 202.

286. A Magnet ***is a body that has the property of attracting iron or steel, and that, when freely suspended, tends to take a definite position, pointing approximately north and south.***

(*a*) One of the most valuable iron ores is called magnetite (Fe_3O_4). Occasional specimens of magnetite attract iron. Such a specimen is called a *lodestone*. It is a natural magnet.

(*b*) Artificial magnets have all the properties of natural magnets, and are more powerful and convenient. They may be temporary or permanent. Temporary magnets are made by passing electric currents around soft iron, as in Experiment 188, and are called electro-magnets. Permanent magnets are made of hardened steel, as in Experiment 189. The most common form of artificial magnets are the *bar magnet* and the *horseshoe magnet*. The first of these is a straight bar of iron or steel; the second is U-shaped, as shown in Fig. 203. A piece of iron placed across the two ends of a horseshoe magnet is called an *armature*. The process of making a magnet is called *magnetization*.

FIG. 203.

(*c*) It appears that matter is subject to the magnetic force as universally as it is to the force of gravitation. Substances that are attracted, as iron is, are called *paramagnetic*, or magnetic; substances that are repelled, as bismuth is, are called *diamagnetic*.

287. Magnetic Poles. — We have seen that when a bar magnet is dipped into iron filings, the magnetic effect is greatest at the ends of the bar, that it diminishes rapidly toward the middle, at which point no filings are sustained, and that the ends of the freely suspended magnet point

toward the poles of the earth. It is common to put a distinguishing mark on the end that turns toward the north, and to call it the marked, north-seeking, or + pole. The other end is called the unmarked, south-seeking, or – pole. The line that joins the poles of a freely suspended magnet is called the magnetic axis. *A unit magnetic pole is a pole that exerts a force of one dyne upon a like pole at a distance of one centimeter.*

(*a*) A unit magnetic pole, i.e., a pole of unit strength, is sometimes said to be of unit *magnetic mass.*

Magnetic Needles.

Experiment 191. — Repeat Experiment 15 using the sewing-needle of Experiment 189. The needle will assume a north and south position.

Experiment 192. — Straighten a piece of watch-spring about 15 cm. long by drawing it between thumb and finger. Heat the middle of this steel bar to redness in a flame and bend it double. Bend the ends back into a line with each other, as shown in Fig. 204. Magnetize each end separately and oppositely. Wind a waxed thread around the short bend at the middle to form a socket, and balance the needle upon the point of a sewing-needle thrust into a cork. A little filing, clipping, or loading with wax may be necessary to make it balance. The needle will point north and south.

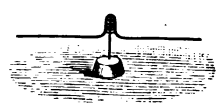

FIG. 204.

Experiment 193. — Pass a knitting-needle through a small cork from end to end and so that the cork shall be at the middle of the needle. Thrust a sewing-needle or half of a knitting-needle through the cork at right angles to the knitting-needle, to serve as an axis of support. Place the ends of the axis upon the edges of two glass goblets or other convenient objects. Push the knitting-needle through the cork until it balances upon the axis like a scale-beam. Magnetize the knitting-needle, and notice that the marked end seems to have become heavier.

288. Magnetic Needles.—*A small bar magnet suspended in such a manner as to allow it to assume its chosen position relative to the earth is a magnetic needle.*

(*a*) If the needle turns freely in a horizontal plane, it is a horizontal needle; e.g., the mariner's or the surveyor's compass. If it turns freely in a vertical plane, it constitutes a *dipping-needle* (Fig. 205). Two magnets fastened to a common axis, and with their poles reversed, constitute an *astatic needle* (Fig. 206). An astatic needle assumes no particular direction with respect to the earth if the two needles are equally magnetized.

FIG. 205.

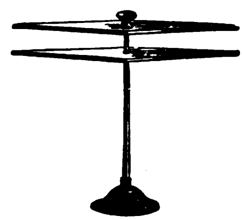

FIG. 206.

Magnetic Field.

Experiment 194.—Lay a bar magnet on the table between two wooden strips of the same thickness as the magnet. Cover the magnet with a sheet of paper or cardboard, or a plate of glass. With a dredge-box or muslin bag, sprinkle uniformly over the plate the finest filings of wrought iron that you can obtain. Gently tap the plate to facilitate the movement of the filings. They will arrange themselves in lines that seem to proceed from the poles, to curve outward through the air, and to complete their circuit through the magnet, as shown in Fig. 207. Freely suspend a short magnet (e.g., a piece of a magnetized sewing-needle supported by a silk fiber) just above the filings, and move it into different positions. At every point, the magnet will place itself parallel to a tangent to the curves, with its marked end always pointing in the same direction relative to the curves.

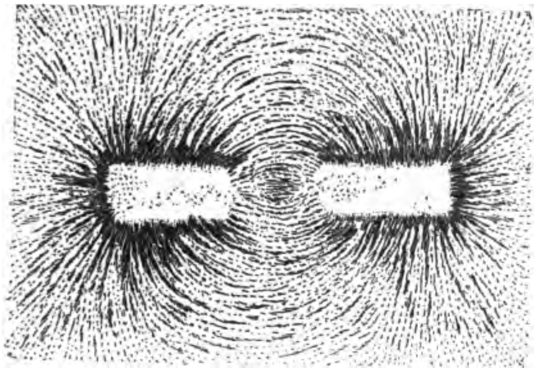

FIG. 207.

Experiment 195.—Similarly map out the "magnetic phantom" curves when the opposite poles of two bar magnets are brought near each other. The result will be like that represented in Fig. 208. The lines from one magnet seem to interlock with those from the other as if by mutual attraction.

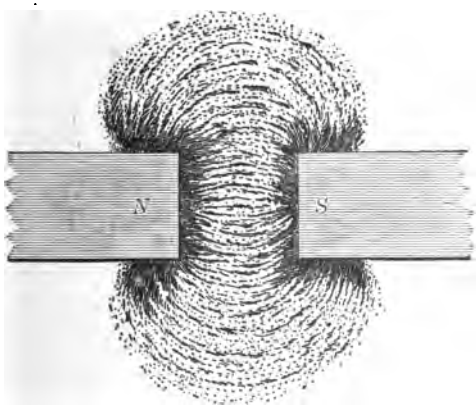

FIG. 208.

Experiment 196.—Similarly produce the phantom when the like poles of two bar magnets are brought near each other. The result

will be like that represented in Fig. 209. The lines now seem to repel each other.

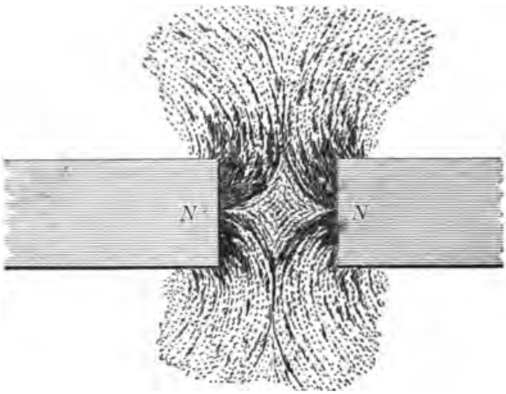

FIG. 209.

289. Magnetic Field and Lines of Force. — *The space surrounding a magnetized body and through which the magnetic force acts is called a magnetic field.* We may imagine lines drawn in the magnetic field, each indicating the direction in which a marked pole would move. *Such lines are called magnetic lines of force.*

(*a*) The magnetic action that takes place in a magnetic field has been happily illustrated by supposing the lines of force to be stretched elastic threads that tend to shorten along their lengths, and that are self-repellent. This suggests that unlike poles ought to attract each other (see Fig. 208), and that like poles ought to repel each other (see Fig. 209). These lines of force are assumed to flow from the marked to the unmarked pole outside the magnet, and in the opposite direction inside the magnet, so as to form closed loops, or complete circuits. By agreement among physicists, as many lines are drawn through each square centimeter of surface as there are dynes in the force of that part of the field.

(*b*) A number of lines of force traversing a magnetic field is called a flow or *flux of force. The unit of flux is called a weber,* and represents one line of force. *The unit of strength of field, or intensity of flux,*

is called a gauss, and represents the number of lines of force per square centimeter. With a flux of 24,000 webers in 12 square centimeters, the intensity of flux would be 2,000 gausses. A field is of unit strength when a unit magnetic pole placed in it is acted upon with a force of one dyne.

Laws of Magnets.

Experiment 197. — Suspend one of the bar magnets at a considerable distance from the others. Bring one end of another magnet held in the hand near one end of the suspended magnet, and notice the attraction or repulsion. Also notice the designations of the poles that are brought into proximity. Satisfy yourself that —

N repels N,	N attracts S,
S repels S,	S attracts N.

290. Law of Magnetic Poles. — (1) *Like magnetic poles repel each other; unlike magnetic poles attract each other.*

(2) *The force exerted at different distances between two poles of the same magnetic mass is inversely proportional to the squares of the distances.*

(3) *The force exerted at a given distance between two poles is directly proportional to the product of the magnetic masses of the poles.*

291. Magnetic Potential is essentially analogous to electrostatic potential. At any point, it is measured by the work done against the magnetic forces in moving a unit magnetic pole from an infinite distance to the given point. The difference of magnetic potential between two points is measured by the amount of work required to move a unit magnetic pole from one to the other. If this work is one erg, there is unit difference of potential between the two points.

292. Magnetization. — Any magnetic substance is magnetized by bringing it into contact with a magnet, or simply by placing it in a magnetic field. In the latter

case, it is said to be magnetized by *induction*. The amount of magnetization developed depends upon the nature of the substance and the strength of the field.

(*a*) With a given field, iron receives the greatest amount of magnetization, steel coming next. As the magnetizing force increases, the magnetization produced also increases, rapidly at first but more and more slowly. When the magnetization ceases to increase, the substance is said to be *saturated*.

Theory of Magnetization.

Experiment 198. — Magnetize a piece of watch-spring about 10 cm. long, and ascertain how large a nail it will support. Break the magnet at its middle, and test the strength of magnetization of the two new poles developed at the point of fracture.

Experiment 199. — Nearly fill a slender glass tube with steel filings, and close the ends of the tube with corks. Draw the marked pole of a strong magnet from the middle of the tube to one end, and the unmarked pole from the middle to the other end, and repeat the stroking several times. One end of the tube will attract and the other will repel the marked pole of a suspended magnetic needle; i.e., the filled tube has become a magnet. Thoroughly shake up the filings; the tube loses its magnetic properties, as if the actions of the many little magnets in the tube were neutralized through their indiscriminate arrangement.

293. Theory of Magnetic Polarization. — When a magnet is broken, each piece becomes a magnet, the newly developed poles being of strength nearly equal to that of the original poles. The subdivision of the magnet may be carried on indefinitely, and with like results. This suggests that *the molecules of a magnetic substance are always magnets; that the substance does not exhibit magnetic properties when the magnetic axes of the molecules are turned indifferently in every direction; and that the process of magnetization consists in turning the molecules so that their magnetic axes point in the same direction.*

Magnetic Properties of Electric Currents.

Experiment 200. — Dip a short part of a stout copper wire that is carrying a large current into fine iron filings. A cluster of the filings will cling to the wire.

Experiment 201. — Repeat Experiment 182, and test the accuracy of the following rules: —

(1) To determine the direction of the deflection of the needle, hold the open right hand over or under the conducting wire, but so that the wire is between the hand and the needle, so that the palm of the hand is toward the needle, and so that the fingers point in the direction of the current; *the marked end of the needle will turn in the direction of the extended thumb.*

(2) To determine the direction of the current, hold the open right hand over or under the conducting wire, but so that the wire is between the hand and the needle, so that the palm of the hand is toward the needle, and so that the thumb is extended in the direction in which the marked end of the needle is deflected; *the fingers will point in the direction of the current.*

NOTE. — If you cannot obtain an electric-light or a trolley-wire current for the next experiment, connect a number of similar cells in parallel. Make the external circuit of very heavy wire, and have the paper in place around the wire, and the dredge-box ready. Close the circuit and perform the experiment quickly.

Experiment 202. — Around a vertical conductor carrying a heavy current, place a piece of paper, and sprinkle fine iron filings on the paper. Notice that the iron particles arrange themselves in distinct circular whirls around the wire, as shown in Fig. 210. Hold the closed right hand so that the extended thumb points in the direction of the current in the wire; then the fingers will indicate the direction of the lines of force in the surrounding field. Bend the upper part of the conducting wire, and pass it vertically downward through the paper. Sprinkle iron filings as before. Notice that the magnetic lines of force around the two parallel parts of the wire circle in opposite directions, clockwise in one case, and counter-clockwise in the other.

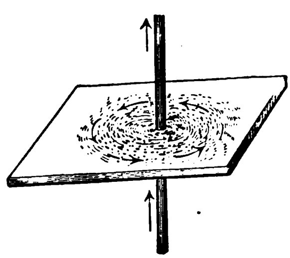

FIG. 210.

Experiment 203. — Coil some No. 12 copper wire through holes in a board, as shown in Fig. 211, and pass a strong current through it. Sprinkle iron filings as before and note the effect. Such a coil of conducting wire, wound so as to afford a number of equal and parallel circular electric circuits arranged upon a common axis, is called a *solenoid.*

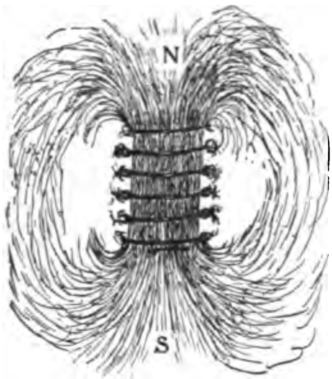

FIG. 211.

Experiment 204. — Wind the middle part of about 3 meters of No. 20 insulated copper wire around a rod about 1.5 cm. in diameter, forming thus a solenoid about 10 cm. long. Bring the ends of the wire along the axis of the solenoid, and bend them at right angles near the middle. Solder small plates of sheet copper and amalgamated sheet zinc to the ends of the wire. Support the solenoid and plates by a large flat cork on the surface of dilute sulphuric acid, as shown in Fig. 212. The floating cell will take position so that the axis of the solenoid extends north and south. Test the ends of the solenoid for polarity, using a bar magnet for that purpose.

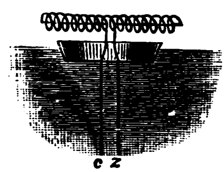

FIG. 212.

Experiment 205.—Prepare a second solenoid similar to that described in Experiment 204, omitting the plates. Put it into an electric circuit, and use it as you did the bar magnet in Experiment 204.

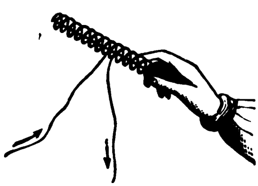

FIG. 213.

294. The Magnetic Character of an Electric Current has been shown by several experiments. The passage of an electric current through a solenoid gives it many of the properties of a cylindrical bar magnet.

(*a*) The polarity of the solenoidal magnet may be determined by holding it in the right hand so that the fingers point in the direction

of the current; then the extended *thumb will point toward the marked or north-seeking pole of the magnet.*

(*b*) The influence to which these magnetic lines of force are due is called *magnetomotive force* (M.M.F.). The magnetomotive force of a magnetic circuit is directly proportional to the number of amperes in the electric circuit surrounding it, and to the number of turns that the electric circuit makes around the magnetic circuit; i.e., *the magnetomotive force is proportional to the ampere-turns.* The unit of magnetomotive force is called a *gilbert*, and corresponds to 0.7958 ampere-turns.

Permeability.

Experiment 206. — Place a strip of sheet iron in the solenoid of Experiment 203, as shown in Fig. 214, and repeat that experiment. Notice that most of the lines of force are gathered into the iron and issue from its ends. Notice that the lines curve outward and tend to return, forming closed loops or complete magnetic circuits. Change the iron from the inside of the solenoid to the outside, and repeat the experiment. Notice that the iron again gathers in the lines of force as if it offered an easier path for them.

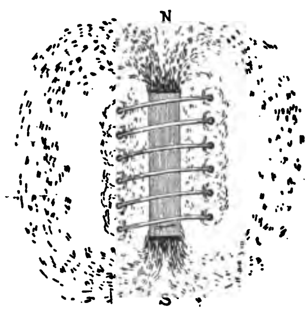

FIG. 214.

295. Permeability. — Some substances are capable of receiving more lines of force than others with the same magnetomotive force. This relative capacity is called *permeability.*

(*a*) Permeability is a ratio. For paramagnetic substances, it is greater than unity; for diamagnetic substances it is less than unity. When a paramagnetic substance is placed in a uniform magnetic field, an increased number of lines of force are crowded into it, as shown in Fig. 215. When a diamagnetic substance is

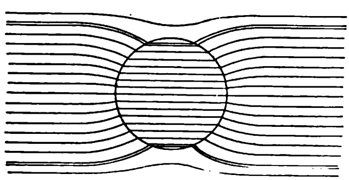

FIG. 215.

placed in such a field, the number of lines that pass through it is diminished.

(*b*) If a small compass is put into a glass bottle, an outside magnet will affect it, but if it is put into a hollow iron ball, an outside magnet will not affect it. *Soft iron acts as a magnet screen because of its high permeability.* Watches are sometimes protected from magnetic influence by soft iron shields in the shape of inside cases.

296. Reluctance and Reluctivity. — Like electric currents, magnetic lines of force flow in the greatest quantity through paths of least resistance. Magnetic resistance is called *reluctance*, and its unit is the *oersted.* Specific magnetic resistance (specific reluctance) is called *reluctivity.* Reluctivity is the reciprocal of permeability.

(*a*) The relations of these magnetic units are expressed by the equation, —

$$webers = \frac{gilberts}{oersteds}.$$

Electromagnets.

Experiment 207. — Make a helix about 15 cm. long by neatly winding three layers of No. 18 insulated copper wire upon a rod about 2 cm. in diameter. Remove the rod, pass a few threads through the opening of the helix, and tie them on the outside so as to hold the turns of wire in place. Put the helix into the circuit of a voltaic cell, and bring it near a magnetic needle. The deflection of the needle shows the magnetic power of the helix. Nearly fill the opening in the helix with straight pieces of soft iron wire, and again test its magnetic power. The deflection of the needle will be much greater than before.

297. An Electromagnet *is a bar of iron magnetized by an electric current.*

(*a*) When the current was passed through the helix used in Experiment 207, some of the lines of force leaked out at the sides, as indicated by Fig. 216, and few of them extended from end to end. The soft iron core, by reason of its high permeability, diminished this leakage of lines of force, and greatly increased their number, as ·n in Fig. 217.

(*b*) When an electromagnet is U-shaped, the coils around the two ends of the bent iron core are so wound that if the core should be straightened either coil would appear as a continuation of the other, i.e., the current would circle around the core in the same direction in the two coils, as is shown in Fig. 218.

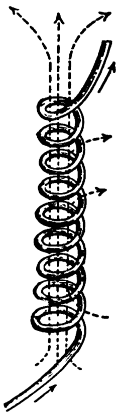

FIG. 216.

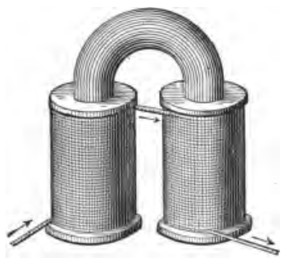

FIG. 218.

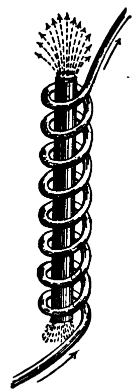

FIG. 217.

(*c*) If the iron of the magnet core is of commercial quality, it is not wholly demagnetized when the current is interrupted. The magnetization thus retained after withdrawal from a magnetic field is called *residual magnetism.*

298. Ampere's Theory of Magnetism.—As an electric current is surrounded by a whirl of lines of magnetic force, so we may conceive a magnetic line of force as surrounded by an electrical current-whirl. This would imply, as Ampere long ago suggested, that magnetism is simply a vortical electric current, and that a magnetic field is something like a whirlpool of electricity.

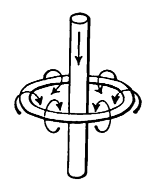

FIG. 219.

(*a*) Fig. 219 represents a vertical conductor carrying an electric current, and surrounded by a magnetic line of force, which is in turn surrounded by electric whirls; *the magnetic line of force is an electric vortex-ring.* It is not difficult to conceive the vortex-ring as made up of ether whirls. Ampere's theory supposes that electric currents circle round the mole-

cules of a magnetic substance, thereby polarizing them, and that when all the molecular magnetic axes face in the same direction the substance is magnetically saturated.

Terrestrial Magnetism.

Experiment 208. — Place a small dipping-needle over the marked end of a long, horizontal bar magnet, and move it slowly toward the other end of the bar, observing the changes in the position of the dipping-needle. Similar changes would be observed if you could carry the dipping-needle from far southern to far northern latitudes.

Experiment 209. — Take a bar of very soft iron about 75 cm. long, and make sure by trial that its ends will not attract bits of soft iron. Then hold the bar in a meridian plane, and with its north end depressed below the horizon a number of degrees approximately corresponding to the latitude of the place of the experiment, i.e., give it the position of a dipping-needle. Tap the rod on its end with a mallet or wooden block, and test it for magnetic polarity.

299. Terrestrial Magnetism. — The directive tendency of the compass, and other phenomena, show that the earth is surrounded by a magnetic field. In fact, these phenomena are such as might be expected if we knew that a bar magnet four or five thousand miles long extended nearly north and south through the earth's center.

(*a*) The angle that the axis of a dipping-needle makes with a horizontal plane is called the *inclination* or *dip* of the needle. The dip is 90° at the magnetic poles of the earth, and 0° at the magnetic equator, and, at any given place, does not differ greatly from the latitude. Lines passing through points on the earth's surface where the inclination has the same value are called *isoclinic lines.* The inclination of the needle is subject at most places to periodic changes.

(*b*) The angle that the axis of a compass-needle makes with the geographical meridian at any place is called the *declination* or *variation* of the needle at that place. When the marked end of the needle lies east of the meridian, the variation is easterly, and vice versa. Lines drawn through places on the earth where the declination is the same are called *isogonic lines,* as is shown in Fig. 220. The particular iso-

gonic line for which the declination is zero is called an *agone* or an *agonic line*. In 1890, the American agone entered the United States near Charleston. It is slowly moving westward. The declination of the needle is subject to both periodic and irregular changes.

(*c*) The magnetic intensity of the earth also varies from point to point at the same time, and from time to time at the same place. Lines drawn through places on the earth where the force of terrestrial magnetism is the same are called *isodynamic lines*.

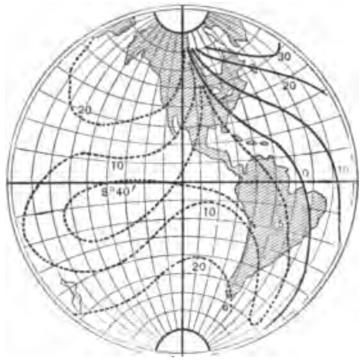

FIG. 220.

EXERCISES.

1. What part of a magnet might properly be designated by the term "equator"?

2. Show that the influence of the earth's magnetism upon a magnetic needle is merely directive.

3. If a wire coil of 220 turns carries a 3-ampere current, what is its magnetomotive force? *Ans.* 829 + gilberts.

4. Float a magnet on water. The float should be the lightest that will carry the load with safety, and the body of water should be so large that surface tension will not urge the float toward the side of the vessel. When the magnet is at rest near the middle of the liquid surface, determine the tendency of the magnet to drift toward the north or south. Repeat the experiment with a variety of magnets, and try to find one that always floats in one direction, i.e., one in which the marked pole is stronger or weaker than the other. If you cannot find such a magnet, strongly magnetize the blade of an old hack-saw, and test it on the float. If you have not yet found that for which you seek, break the blade in the middle, and test each half. If necessary to the success of your search, break one of the halves in two, and repeat the tests. Make very careful notes of any magnet that you find to have more magnetism of one kind than of the other.

5. Map a magnetic field as in Experiment 194. Carefully remove the magnet and wooden strips. Over the filings, carefully place a sheet

of printing-paper that has been wet with a solution of tannin. Over this, place a sheet of heavy blotting-paper. Place a board on the blotting-paper and a weight on the board. When the printing-paper is removed, some of the iron filings will adhere to it. When the paper is dry, brush off these filings. The ink-like markings on the paper make a permanent copy of the map.

II. ELECTRIC GENERATORS, ELECTROMAGNETIC INDUCTION, ETC.

NOTE. — The devices considered in the preceding section are incapable of producing a current adequate to the demands of the age in which we live. It is the purpose of this section to indicate how such currents are produced.

300. Voltaic Cells are the most common "electric generators," and have been devised in great variety. Some of them are dry, some have one liquid, and others have two. Some are constant and strong while they last, but require frequent renewals; others are effective for short periods only, and require time for their own recovery. Each has its advantages and its disadvantages, so that one is the better for one purpose, and another for another.

(*a*) When commercial zinc is used as one of the plates of a cell, much of the energy of the cell is wasted in what is known as *local action*. This is probably due to chemical action between particles of zinc and adjacent particles of carbon, iron, etc., that are present as impurities in the zinc. It is easy to imagine minute voltaic cells, the currents flowing in short circuits from the zinc through the liquid to the foreign particles, and thence back to the zinc. This local action is prevented by using pure zinc, or by amalgamating commercial zinc as in Experiment 180.

(*b*) The *polarization* of the cell, i.e., the accumulation of the hydrogen film on the negative plate, diminishes the available current by increasing the resistance of the circuit, and by setting up a counter electromotive force that may reduce, stop, or even reverse the flow of the current. The various devices for removing the hydrogen, or for

preventing its accumulation, constitute the most essential differences between the different forms of cells.

(*c*) A few forms of cells are mentioned; it is impossible to give descriptions of all or many. *The oxidation of hydrogen yields water.*

(1) The *potassium dichromate* cell (see Experiment 182) consists of zinc and carbon plates immersed in a solution of potassium dichromate in dilute sulphuric acid. The action of the sulphuric acid on the dichromate liberates chromic acid which oxidizes the hydrogen, and thus prevents polarization. This cell is very convenient for quick use, and valuable for "all-around" work. It is sometimes called the *Grenet* cell. A similar cell that employs *sodium dichromate* instead of potassium dichromate is more enduring in its action. A solution of chromic acid is much used and is more economical than either.

(2) In the *Grove* cell, a cylindrical plate of zinc is immersed in dilute sulphuric acid, and carries a porous cup that contains strong nitric acid in which a platinum strip is immersed. The hydrogen evolved at the zinc plate is oxidized by the nitric acid.

(3) The *Bunsen* cell differs from the Grove in a substitution of carbon for platinum, and in the larger size of the plates. Like the Grove cell, it is little used now, the fumes that come from the nitric acid being choking and corrosive.

(4) In the *Leclanché* cell, a zinc rod is immersed in a saturated solution of ammonium chloride (sal-ammoniac). In this solution is also a porous cup that contains a bar of carbon tightly packed in a mixture of granular carbon and manganese dioxide. The hydrogen evolved is oxidized by the dioxide, but so slowly that the cell must be given frequent intervals of rest to recover from polarization. This cell is much used for working telephones, electric bells, etc., i.e., on circuits that are open most of the time.

(5) The *Daniell* cell consists of a zinc plate immersed in dilute sulphuric acid contained in a porous vessel outside of which is a perforated copper plate surrounded by a solution of copper sulphate. The hydrogen is taken up by the sulphate before it reaches the copper plate. Polarization being wholly prevented, this cell is one of the most constant known.

(6) The *gravity* cell is a modification of the Daniell. The liquids are kept separate by their different densities, thus dispensing with the porous cup. It is commonly used on closed circuits. This is the form of cell most used for telegraphic purposes.

(*d*) Every cell has an internal resistance that consists chiefly of the

resistance of the liquid or liquids used. The voltage of the cell is largely taken up in overcoming this internal resistance, thus greatly lessening the energy available. If R is the resistance of the circuit outside the cell, and r is the resistance of the cell itself, then Ohm's law becomes

$$C = \frac{E}{r + R}.$$

Refer to Fig. 193, and notice that the liquid prism between the plates is part of the circuit; that when the plates are separated, the length of the liquid conductor, and the internal resistance of the cell, are increased (see § 277); that when one of the plates is lifted partly from the liquid, the area of cross-section is reduced, and the resistance increased.

The Grouping of Cells.

Experiment 210. — Upon each end of a 4-inch piece of soft, round iron rod 1 inch in diameter, drive a vulcanite or hard-wood collar about $1\frac{1}{2}$ inches in diameter. Upon the spool thus formed, wind about 6 feet of No. 8 insulated copper wire, being careful first to insulate the iron core with paper. Fasten a rectangular piece of soft iron, a, to a piece of whalebone, and support it, as shown in Fig. 221, over M, the electromagnet just described.

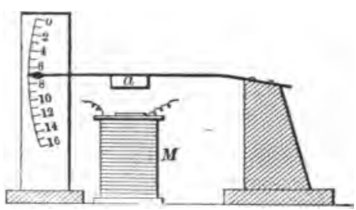

FIG. 221.

Place M in the circuit of a battery of six or more similar cells joined in series. The whalebone magnetoscope will enable you to make a rough estimate of the pull of the electromagnet. Connect the cells of the battery in parallel, and repeat the experiment.

Experiment 211. — Connect the terminals of a high resistance galvanoscope to the poles of a single cell, and record the deflection of the needle. Next, put the galvanoscope in circuit with a battery of six similar cells joined in parallel, and record the deflection of the needle. Then put the galvanoscope in circuit with a battery of the same cells joined in series, and record the deflection of the needle. From the records, determine which method of joining cells is most effective with a high external resistance.

301. Advantages of Grouping in Parallel. — Some of the foregoing experiments indicate what is a general truth, that, when the external resistance is small, the grouping of electric generators in parallel will give a greater current than will a series grouping of the same generators.

(*a*) With such a grouping, the available difference of potential between the terminals of the system is not increased, but the internal resistance is diminished.

302. Advantages of Grouping in Series. — Our experiments also indicate that when the external resistance is great, the grouping of electric generators in series will give a greater current than will a parallel grouping of the same generators.

(*a*) With such a grouping, the voltages of the several generators are added together for the total available difference of potential, and the internal resistances are added together for the total internal resistance of the system.

(*b*) Having a given number of similar cells and a certain known external resistance, the maximum current may be obtained by joining the cells in such a way as to make the resistance of the battery as nearly equal as possible to the resistance of the external part of the circuit.

EXERCISES.

1. Determine the current strength of a battery of 5 cells joined in parallel, each having an E.M.F. of 2 volts and an internal resistance of 0.5 ohm, (*a*) when the external resistance is 0.1 ohm; (*b*) when the external resistance is 500 ohms. *Ans.* (*a*) 10 amperes.
(*b*) Nearly 0.004 ampere.

2. Determine the current strength of a battery made up by coupling the same 5 cells in series, (*a*) when the external resistance is 0.1 of an ohm; (*b*) when the external resistance is 500 ohms.
Ans. (*a*) 3.846 + amperes; (*b*) 0.0199 + of an ampere.

3. Connect in parallel 8 voltaic cells, each having an E.M.F. of 2 volts, and an internal resistance of 8 ohms, the total external resistance being 16 ohms. Determine the current strength.
Ans. 0.1176 of an ampere.

4. Compute the current strength of the same 8 cells connected in series, the external resistance remaining the same. *Ans.* 0.2 ampere.

5. Compute the current strength of the same 8 cells when joined in two rows, each row being a series of four cells, and the rows being joined in multiple arc, the external resistance remaining the same. *Ans.* 0.25 ampere.

6. Each of ten given cells has an electromotive force of 1 volt and an internal resistance of 5 ohms. What is the current strength of a single cell, the external resistance being 0.001 of an ohm? *Ans.* 0.19996 + ampere.

7. The ten cells above mentioned are joined in parallel. The external resistance is 0.001 of an ohm. What is the current strength of the battery? *Ans.* 1.996 + amperes.

8. The ten cells above mentioned are joined in series, the external resistance remaining the same. What is the current strength of the battery? *Ans.* 0.19999 + ampere.

9. What is the current strength given by one of the above-mentioned cells when the external circuit has a resistance of 1,000 ohms? *Ans.* 0.00099502 ampere.

10. When the ten cells are joined in parallel with an external resistance of 1,000 ohms, what is the ampere yield of the battery? *Ans.* 0.0009995 ampere.

11. When the ten cells are joined in series with an external resistance of 1,000 ohms, what is the current strength of the battery?

NOTE.—Compare the results in Exercises 6, 7, and 8, in which we have a small external resistance. Then compare the results in Exercises 9, 10, and 11, in which we have a high external resistance.

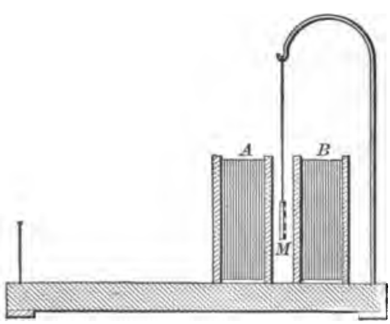

FIG. 222.

Electromagnetic Induction.

Experiment 212. — For a galvanoscope more delicate than any we have yet used, procure two soft pine blocks, 4 cm. square and 2 cm. thick. On the square faces of each, nail or glue a thin piece of wood, 6 cm. square. (These pieces may be cut from a cigar box.) The channel around the edges of the

blocks will be 2 cm. wide and 1 cm. deep. Through the middle of each block, from face to face, bore a hole at least 1.5 cm. in diameter. Wind the grooves full of No. 36 insulated copper wire, and mount the blocks, *A* and *B*, on a baseboard with their opposing faces about 1 cm. apart, as shown in Fig. 222. Connect the wires of the two coils so that a current flowing through the wire will circle around the coils in the same direction; i.e., connect them in series.

Straighten and magnetize four or five pieces of watch-spring each 1.5 cm. long, and fasten them with thin shellac varnish to the back of a piece of looking-glass, 1.5 cm. square and as thin as you can get (see Fig. 223). From a support made of brass wire, suspend the mirror, *M*, by a strand of silk, the lightest that will carry the load. A single silk fiber may be strong enough. The mirror when suspended should hang midway between the two coils, and directly in line with the holes through the two coils. So adjust the base of the galvanoscope that the coils are parallel to the mirror when the latter is freely suspended between them, and protect the apparatus from air currents by a glass cover. A feeble current passing through the coils will deflect the delicately suspended needles, as was roughly illustrated in Experiment 182. By placing a bar magnet on the table so as partly to neutralize the directive tendency of the terrestrial magnetism, the sensitiveness of the galvanoscope may be increased.

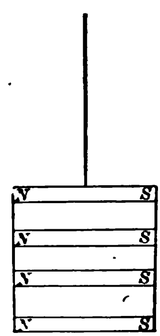

Fig. 223.

Stick a pin into the end of the base-board and in line with the centers of the openings in the coils, as appears more plainly in Fig. 224. The eye may be so placed that the pin will cover its image in the mirror. The slightest deflection of the mirror will be manifested by the destruction of this coincidence. Indicate the polarity of the suspended magnets by marking the letters *N* and *S* near the edges of the base-board between the coils *A* and *B*. Put the galvanoscope into circuit with a single cell, and note the deflection of the mirror. Record on the base-board of the instrument the fact that "This instrument shows a deflection of the *N* end of the needle toward the east when the zinc plate of a cell is connected with the free terminal of coil *B*" (or of *A*, as the case may be).

Experiment 213. — Make a coil with many turns of No. 36 insulated copper wire, as shown at *H* in Fig. 224. The coil should have an

internal diameter of about 3 cm., and a cross-section area of at least 1 sq. cm. Connect the terminals of the coil with the terminals of the galvanoscope. Level the galvanoscope, and see that its needle-mirror is freely suspended as directed in the preceding experiment. Thrust

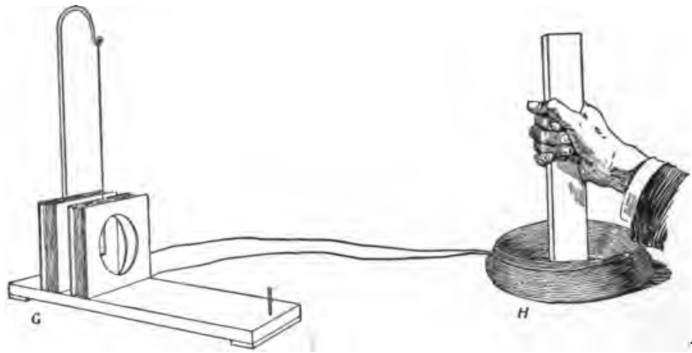

FIG. 224.

the end of a bar magnet at least 1.5 cm. in diameter into the coil, *H*, thus filling the coil with lines of force. An electric pulse deflects the mirror of the galvanoscope. That the deflecting current was of momentary duration is shown by the fact that the mirror returns to its first position. When it has come to rest, remove the magnet from the coil. The mirror is turned the other way and comes to rest as before, thus showing that the direction of the second current was opposite to that of the first, and that its duration was but momentary. Repeat the experiment, making the motions of the magnet more rapid. Notice that the pulses are more marked than before. Repeat the experiment again, using a low resistance solenoid that carries a current of electricity, as shown in Fig. 225, instead of the bar magnet. Then place the solenoid inside the coil, *H*, and break, and make the battery circuit. Place a soft iron rod inside the solenoid and again break and make the circuit, noticing any increase in the deflections of the needle.

FIG. 225.

That the galvanoscope may be free from disturbing magnetic influence, see that all knives, keys, watches, and other articles of iron

or steel are kept at a considerable distance from it, and that the coil, *H*, is so far removed that the magnet or the solenoid may not have any perceptible direct influence upon it. It will be well to wind the wire of the coil, *H*, upon a spool.

Experiment 214. — Place the coil, *H*, in circuit with a telephone receiver instead of the galvanoscope. When the circuit of the solenoid is made or broken, a distinct click may be heard in the receiver, which is a delicate detector of pulses of electricity. The telephone may be bought at a low price, or borrowed.

FIG. 226.

303. Induced Currents. — When the number of magnetic lines of force that pass through a closed coil of wire is changed, as in Experiment 213, pulses of electricity are generated in the coil. The rapidity with which the coil is filled with lines of force, or emptied, has a marked effect upon the intensity of the pulses generated. *These momentary currents are said to be induced in the coil; i.e., they are induced currents.*

304. Laws of Induced Currents. — (1) *An increase in the number of the lines of force passing through a closed coil induces a current in one direction through the wire of the coil; a decrease in the number of the lines of force induces a current in the other direction.*

(2) *The electromotive force of the induced currents depends upon the rapidity of change in the number of lines of force that pass through the coil.*

305. A Magneto *is a device for inducing electric currents in wire coils or bobbins, by variations in the relative positions of the coils and of permanent magnets.*

(*a*) The fundamental process in the generation of electric currents from mechanical power consists in revolving closed conductors in a magnetic field in such a way as to vary the number of lines of force passing through them, i.e., by successively filling and emptying closed

coils. The mechanical motion may move the coils, or the source of the magnetic flux, or it may simply move a mass of iron that forms a ready path for the lines of force. The magneto is of historical interest, but it has been largely displaced by the more efficient dynamo, an electric generator that differs characteristically from the magneto in that the former employs a field of force due to the influence of electromagnets, while the latter utilizes permanent magnets.

306. The Dynamo. — Suppose a single loop of wire to turn upon a horizontal axis, and between the opposite poles of two magnets, *N* and *S*, as shown in Fig. 227. When the loop stands in a vertical plane, as indicated by the heavy black line, the magnetic lines of force between the pole-pieces thread through the loop in the greatest possible number. When the loop has been turned until it lies in a horizontal plane, as indicated by the dotted lines in the figure, the lines of force run parallel to the plane of the loop, and none thread through it. During this quarter revolution of the loop, the number of lines of force that pass through the loop was decreasing, and an electric current was thereby induced in the loop, as indicated by the arrows. During the next quarter revolution of the loop, the number of lines of force threading the loop was increasing, but as they passed through the loop from the other side, the current induced in the loop had the same direction as before. During the next half revolution, the induced current will flow through the loop in the opposite direction. The current, therefore, reverses twice for each revolution of the loop.

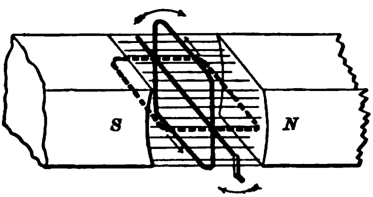

FIG. 227.

(*a*) The direct current dynamo consists essentially of three parts: an *armature* made of coils of wire, which may be revolved in a

magnetic field; a *commutator* for giving a uniform direction to the alternating currents induced in the armature coils; and a large *electromagnet* for creating a magnetic field.

(*b*) Fig. 228 represents the Brush dynamo complete. A shaft runs through the machine from end to end, carrying a pulley, *P*, at one end, a commutator, *c*, at the other end, and a wheel armature, *R*, at the middle. The armature carries eight or more helices of insulated wire, *H H*, connected in pairs. As the shaft is turned by the action of the belt upon the pulley, the armature and the commutator are turned with it. The armature coils are thus carried rapidly across the four poles of

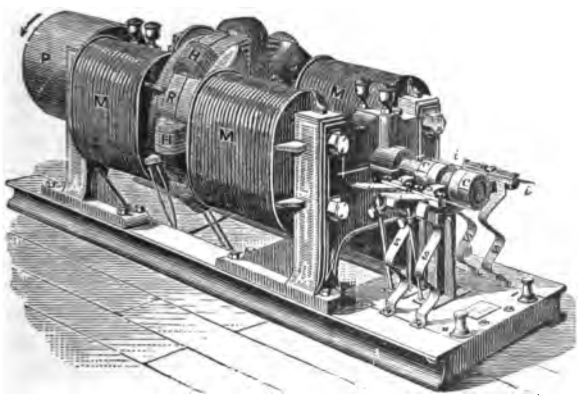

FIG. 228.

the field magnets, *M M*, traversing the intenser parts of the magnetic field, and cutting the lines of force.

(*c*) The alternator is a dynamo designed for the generation of alternating currents. It has collecting rings instead of a commutator, so that the current is delivered just as it is generated (§ 305), and a small direct current dynamo for energizing its field magnets, the pole-pieces of which are generally very numerous. Nikola Tesla has invented an oscillator that is a combined prime motor and electric generator, and that produces alternating currents without rotary motion of the generating coils.

307. An Armature *is a soft iron cylinder or ring upon which coils of insulated copper wire have been wound and arranged for rapid rotation in a magnetic field.*

(*a*) By virtue of its greater magnetic permeability, the soft iron core of the armature increases the number of lines of force gathered into the space traversed by the coil, and thus increases the electric effect. The revolving coil is made of many turns of wire instead of a single loop, and the electromotive force generated by the revolution is correspondingly multiplied.

(*b*) Armatures are of several distinct types, the chief of which are the drum or shuttle armature, and the ring armature. In the former, a cylindrical iron core is made of thin disks of soft iron insulated from each other, thus minimizing the "local" or "Foucault currents,"

FIG. 229.

which are generated in the iron, absorbing energy and transforming it into heat. On the cylinder thus built up, many separate coils are wound lengthwise, as is shown in Fig. 229. These separate coils are joined in series, and the several junctions connected to insulated bars, the extremities of which are grouped around the shaft of the armature, as shown at the left of the figure. Brass bands around the outside of the cylinder hold the coils in place.

FIG. 230.

(*c*) The ring armature consists of coils wound in grooves upon an annular core, as shown in Fig. 230, which represents a partly wound armature for a Brush dynamo. The core is laminated, i.e., built up by winding a thin ribbon of soft iron in successive layers, each layer being insulated from the next. Coils radially opposite are joined in series, and the terminals of each such pair are carried to the commutator.

308. A Commutator *is a device for reversing the connections of armature coils at the moment when the current in the coils is reversed*, thus causing the induced currents to flow in the same direction in the external circuit.

(*a*) A simple commutator for a single-coil armature consists of the two halves of a metal collar around the armature shaft, and two metal strips or "brushes." The two halves of the collar, i.e., the "commutator segments," *m* and *n*, are separated from the shaft, *s*, that carries them by a bushing of insulating material, and are separated from each other, as shown in Fig. 231. One end of the armature coil is connected with one segment, and the other end with the other segment. The brushes, *b b′*, are held by fixed supports so that their free ends rest lightly on the segments. The points of contact are diametrically opposite.

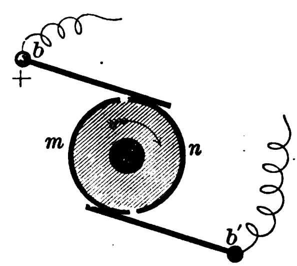

FIG. 231.

Consider *b* and *b′* the terminals of the dynamo, and that they are connected by a wire that constitutes the external circuit. Remember that *m* and *n* are connected through the armature coil. Assume that the connections of the terminals of the armature coil with the commutator segments are such that current flows through the coil and passes out by way of *n* and *b*. As the armature is turned a little further, the current in the coil is reversed, and flows out through *m* instead of *n*. But the same rotation of the shaft that carries both the armature and the commutator has now brought *m* into contact with *b* so that the current continues to flow through *b*, which thus remains the + terminal as long as the shaft is turned in the direction indicated by the arrow. There are many different ways of connecting armature coils with their commutators, each one of which may call for careful study.

309. The Field Magnet. — The electromagnet that supplies the flux of force must have a current to excite it.

(*a*) This current is sometimes supplied from an outside source, as is diagrammatically shown in Fig. 232. Such a dynamo is said tc

be *separately excited.* Often, all of the current from the armature is carried around the coils of the field magnet, thus forming a *series*

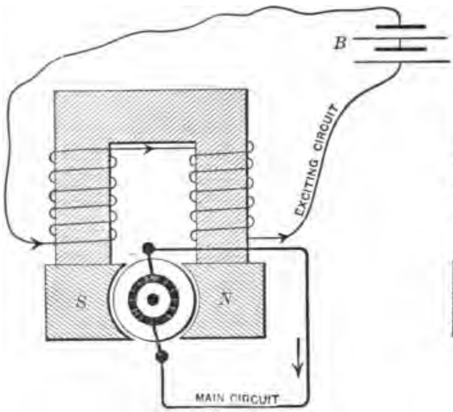

Fig. 232.

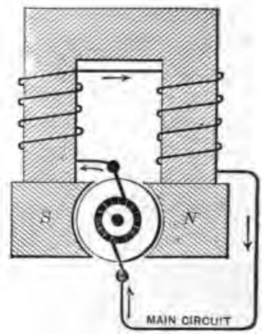

Fig. 233.

dynamo, as is shown in Fig. 233. Sometimes a part of the current from the armature is carried through a shunt circuit consisting of many turns of wire that is smaller than the wire of the main circuit,

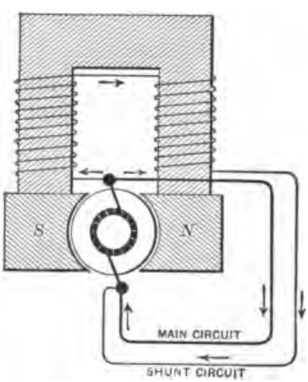

Fig. 234.

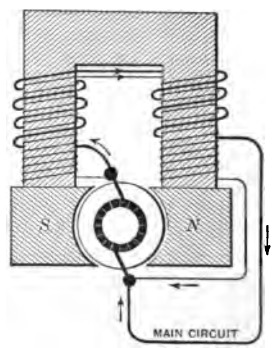

Fig. 235.

as is shown in Fig. 234. Such a dynamo is said to be *shunt wound.* Sometimes, for purposes of regulation, the field magnet is encircled

by both series and shunt coils, as is shown in Fig. 235, or by either of those with a separately excited coil. Such a dynamo is said to be *compound wound.*

(*b*) When the armature of a "self-exciting" dynamo, i.e., one that has not an exciting current from an external source, is put in motion, the feeble *residual magnetism* of the cores of the field magnets induces feeble currents in the armature coils. These currents flow around the magnets, intensifying their power, and thus increasing the E.M.F. of the machine. The current thus strengthened further energizes the field magnet. Thus, the machine "builds up" its current until the magnets are saturated.

EXERCISES.

1. What is an induced electric current? How is it produced?

2. How are induced currents made continuous?

3. Give some proof that the condition of a wire when it closes an electric circuit is different from the condition of the same wire when the circuit is open.

4. Why are the field magnets of dynamos generally provided with iron cores?

5. What is the difference between a magneto and a dynamo?

6. When a dynamo is in operation, its field magnets are likely to become heated. Does this increase or diminish the efficiency of the machine, and why?

7. Given the two electrodes of a concealed voltaic battery, determine which of the wires is connected to the zinc plate.

8. Provide a glass tube of about 1 cm. internal diameter. Insert a wire in each end, and fill the tube with pieces of pounded electric light carbon. Pass a current from a cell through the apparatus, interposing a low resistance galvanoscope. By means of a wooden rod, compress the powdered carbon. Why is the deflection largely increased? Why is a low resistance galvanoscope used?

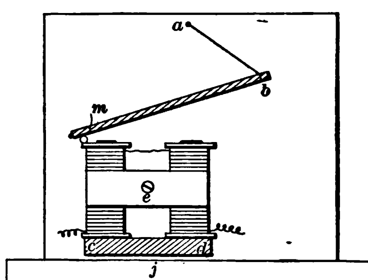

Fig. 236.

9. To a vertical board clamp two magnet bobbins (see Exercise 10) joined in series, as shown in Fig. 236. Support one end of the arma-

ture, *bm*, by an elastic band, *ab*. Pass a current through the bobbins, and notice the pull upon *ab*. Looking at the upper ends of the bobbins, notice whether the current circles around the two bobbins in the same direction or not, as clockwise or counter-clockwise. Turn one of the bobbins upside down, changing the connections in this respect. Ascertain which connection gives the greater pull upon the armature, *bm*, and, with the bobbins thus joined, bring the movable soft iron yoke, *cd*, into position as shown in the figure. Explain why this improves the magnetic circuit, so that the upper armature is pulled harder than before, and probably drawn down with a sharp click.

10. Make two magnetoscopes like that shown in Fig. 221. Ordinary carriage-bolts about 7 cm. long may be used as the cores, and soft iron nuts may answer as the armatures. With the two magnetoscopes, a voltaic battery, and a supply of insulated No. 20 copper wire, arrange apparatus so that you can exchange telegraphic signals with another pupil at another table, or in another room.

The Pulsating Current.

Experiment 215. — Mount a metal clock-wheel upon wooden bearings, and solder to its axle a wire crank by which it may be turned. Provide two metal springs. The upper end of one should rest upon the toothed edge of the wheel, and "snap" from one tooth to the next as the wheel is turned. The upper end of the other should rest on the axle of the wheel. Consider the fixed ends of these springs as the terminals of this "interrupter." Put this apparatus into the circuit with a voltaic battery and the galvanoscope that has a coil of No. 16 wire. Turn the wheel, and notice the deflection of the needle.

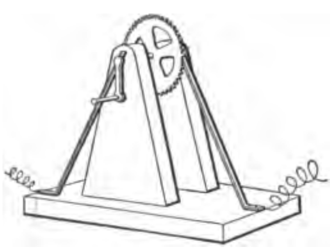

FIG. 237.

310. Alternating Currents have some peculiar properties largely due to the constantly fluctuating field of force that surrounds their conductors. The pulsating current produced by the interrupter has many of the properties of the alternating current, and will facilitate our investigations.

(*a*) The current does not wholly cease when the spring of the interrupter snaps from tooth to tooth. As the circuit is broken, the encircling magnetic lines of force are decreased in number, and *that very decrease tends to continue the current.* In brief, the current does not have time wholly to die away before the spring is on the next tooth of the wheel.

Self-Induction.

Experiment 216. — Double a piece of No. 24 insulated copper wire about 100 feet long, and wind it upon a wooden rod as shown in Fig. 238. Join the ends of this wire in the series circuit of the apparatus arranged for Experiment 215. Turn the wheel of the interrupter rapidly, and note the deflection of the galvanoscope. Remove the No. 24 wire from the circuit, straighten it, and wind it upon an iron rod so as to form an electromagnet. Put this electromagnet into the circuit, and repeat the experiment. Notice that the deflection of the galvanoscope is less, and that the sparks at the wheel of the interrupter are greater than before.

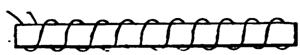

FIG. 238.

311. Self-Induction. — *When the number of lines of force in a coil is increasing, an electromotive force opposite to that of the inducing current is established, thus weakening the direct current; when the number is decreasing, an electromotive force that coincides in direction with that of the inducing current is established, thus strengthening the direct current.*

(*a*) When the doubled wire of Experiment 216 was wound upon the rod, every part of it lay adjacent to another part that was carrying current in the opposite direction. The magnetic lines of force generated by one part neutralized the lines of force that circled (see Fig. 371) in the opposite direction around the adjacent part; i.e., the circuit was non-inductive. When the wire was straightened, the lines of force circled in the same direction around adjacent parts of the wire, and assisted each other in setting up an opposing, self-induced electromotive force that greatly weakened the current that produced them.

(*b*) A coiled circuit is said to have a *reactance.* This reactance

has much the effect of resistance, but it depends upon other considerations, chiefly the frequency of the pulsations, and upon a certain constant called the *coefficient of self-induction.* This coefficient depends upon the shape, coiling, and coring of the circuit and, in practice, is determined only by experiment.

(*c*) As alternating currents are fluctuating in value, their measure must be that of averages. For a true alternating current, the numerical relations may be represented thus: —

$$C = \frac{E}{\sqrt{R^2 + (2\pi nL)^2}},$$

in which R represents the ohmic resistance, n the frequency of alternation, and L the coefficient of self-induction. *The expression* $2\pi nL$ *represents the reactance. The apparent resistance*, i.e., $\sqrt{R^2 + (2\pi nL)^2}$, *is called the impedance, and is measured in ohms.*

Transformers.

Experiment 217. — Wind about twenty turns of No. 18 insulated copper wire around a ½-inch iron rod, or (preferably) around a bundle of iron wires, and put the coil into circuit with a pulsating current. The lines of force inside the coil and in the core fluctuate in value with the current. On the outside of this coil, and carefully insulated from it, wind 300 or 400 feet of No. 28 insulated copper wire. Place one of the terminals of this outer or *secondary coil* above the tongue, and the other terminal below it. When the pulsating current flows through the inner or primary coil, currents are induced in the secondary coil, and produce distinct shocks in the tongue.

312. The Transformer. — By suitably winding and coring primary and secondary coils, an alternate current at one voltage may be received by the primary, and a current at a different voltage delivered from the secondary. When the primary is made of a few turns of large wire, and the secondary is made of many turns of small wire, the voltage is increased, and vice versa. *Coils so wound and properly cored are called transformers.*

(*a*) Transformers are largely used when currents are to be carried great distances. With a given line, the loss in watts is less with

a small current and high voltage than it is with large current and low voltage. High voltage currents enable the use of small conductors; copper wire is expensive. When the electric energy is transformed from a current of low voltage and many amperes to one of high voltage and few amperes, the apparatus is called a "step-up" transformer. Similarly, when the voltage is decreased, the apparatus is called a "step-down" transformer.

313. The Induction Coil is a modification of the apparatus used in Experiment 217, and is often called the Rhumkorff coil. Receiving a large current of small electromotive force, it delivers a small current at a high pressure, sometimes hundreds of thousands of volts, i.e., it is a "step-up" transformer.

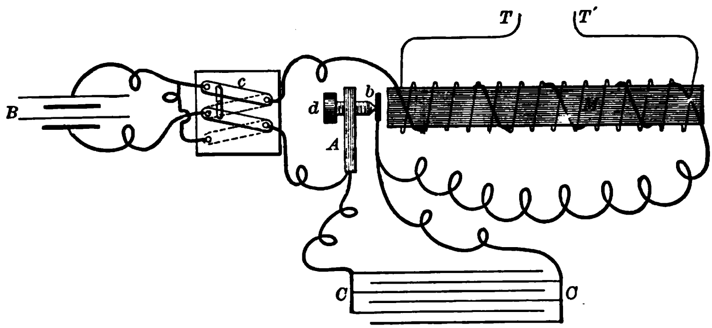

FIG. 239.

(*a*) In the diagram shown in Fig. 239, *M* represents a core of iron wires upon which is wound a primary coil of coarse wire that is in circuit with the voltaic battery, *B*. In this primary circuit, are a commutator, *c*, for changing the direction of the current, and an automatic interrupter, *b*. Wound upon the primary coil, and very carefully insulated from it, is a secondary coil made of very many turns of fine wire, the terminals of which are marked *T T′*. If the coil is designed to give sparks between *T* and *T′*, the condenser, *CC*, is added. This consists of sheets of tin-foil separated by sheets of paraffined or shellac-varnished paper. The alternate sheets of tin-foil are joined in parallel; the two groups are connected to the primary circuit on

opposite sides of the interrupter. The condenser is generally placed in the base that carries the coil.

(*b*) A simple form of the induction coil is shown in Fig. 240. The current passes through the commutator, *c*, up the post, *A*, through the adjusting screw, *d*, and across to the spring interrupter, *b*, which rests against the end of *d*, and is carried by another post. Thence it passes to the primary coil, magnetizing the iron core, and making its way back to the generator. The iron core thus magnetized attracts the soft iron hammer at the end of the spring, thus breaking the circuit at *b*. When the current is broken, the core is demagnetized, and the elasticity of the spring throws *b* against the end of *d*, again making the circuit. Thus the spring vibrates between the end of the core and the end of the screw, making and breaking the circuit with great rapidity, and inducing currents in the secondary coil. Owing to the permeability of the iron core, which intensifies the flux of force through the coils, and to the great number of turns in the wire of the secondary coil, the electromotive force of the induced currents is very high.

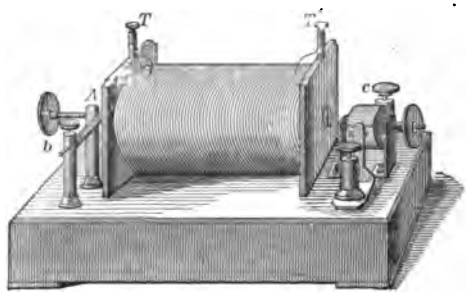

FIG. 240.

High Potential Phenomena.

Experiment 218. — Connect a voltaic battery with the primary of an induction coil. Bring the terminals of the secondary within a few millimeters of each other, and notice the rapid succession of sparks that strike across the gap filled with air, one of the best of insulators. With a good coil, plates of glass and other non-conductors may be thus perforated. We have not noticed this property of electricity before because we have not had a current of sufficiently high E.M.F.

Experiment 219. — In a shallow tin pan (e.g., a common pie-tin), melt equal quantities of rosin and shellac. Stir the substances together, avoid ignition and the formation of bubbles, and, when the

tin is filled, set it aside to cool. Cut a disk of sheet tin a little less in diameter than the resin plate, and fasten a piece of sealing-wax at its center for a handle. Solder a round button or other metal ball on the upper side of the disk and at its edge. Whip the resin plate briskly with a catskin, or rub it with warm flannel. Place the tin disk upon the plate, and touch the former with a finger. Place a number of small bits of paper upon the disk. Lift the disk by its handle; the charged paper bits are repelled. Bring a knuckle to the button; an electric spark may be seen. The disk may be charged many times without repeating the excitation of the resinous plate. The apparatus may be improved by making the disk of wood, rounding its edge, and covering it smoothly with tin-foil.

314. An Electrophorus consists of a plate of resinous material or of vulcanite resting on a metallic bed-piece, and a movable metallic cover provided with an insulating handle.

(*a*) As the surface of the resin plate is uneven, the metallic cover touches it at but a few points; as the material is non-conducting, scarcely any electrification passes from the former to the latter. The two disks and the thin layer of air between them constitute a condenser (§ 268). The negatively electrified resin plate acts by induction on the disk, holding positive electrification "bound" at its lower surface, and repelling the negative which escapes through the finger. When the plate thus charged is removed from the resin plate, the bound electrification is set free.

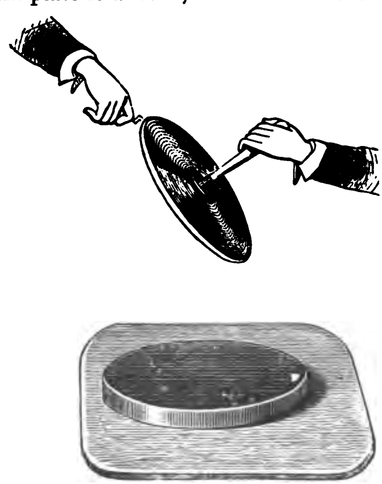

FIG. 241.

315. Electric Machines for developing statical electrification in large quantities depend upon either friction or

induction for their operation, and are made in great variety.

(*a*) The frictional electric machine usually consists of a plate of glass, *A*, which is revolved between stationary cushions, *D*, the surfaces of which are covered with amalgam. The parts of the plate thus positively electrified are successively brought between two metallic combs, *F*, the pointed teeth of which nearly touch the plate. The prime conductor, *P*, is electrified by induction, the negative electrification escaping by air-convection from the pointed teeth to the oppositely electrified plate, thus neutralizing its electrification and

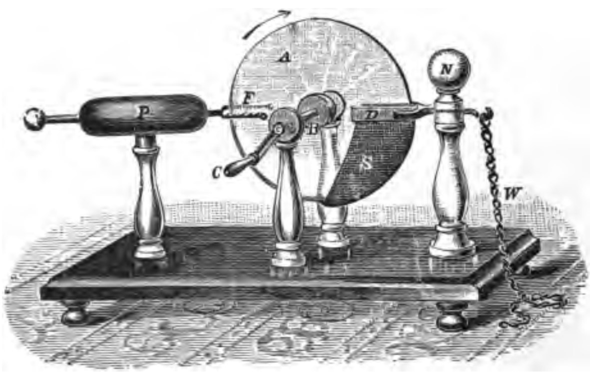

FIG. 242.

leaving the prime conductor positively charged. The negative conductor, *N*, that carries the cushions is generally connected to earth, as shown in Fig. 242. The potential energy of the electrification thus obtained is the equivalent of the kinetic energy expended in turning the crank, minus that transformed into heat.

(*b*) The induction machines may almost be described as continuous electrophori. The Wimshurst machine (Fig. 243), which may be taken as a representative of the class, consists for the most part of two equal glass disks that revolve in opposite directions. Sector-shaped strips of tin-foil are fastened to the outer surfaces of the plates, and act as carriers of electrification and, when opposite each other, as field plates or inductors. Two conductors are placed at right angles to each other, obliquely across the plates, one at the front and the other at the back.

The ends of these conductors carry tinsel brushes that lightly touch the sectors as they pass. The discharging circuit is provided with combs that face each plate, and that are connected with small Leyden jars. The distance between the balls of the discharging circuit may be regulated by insulated handles. This machine is almost wholly free from "weather troubles."

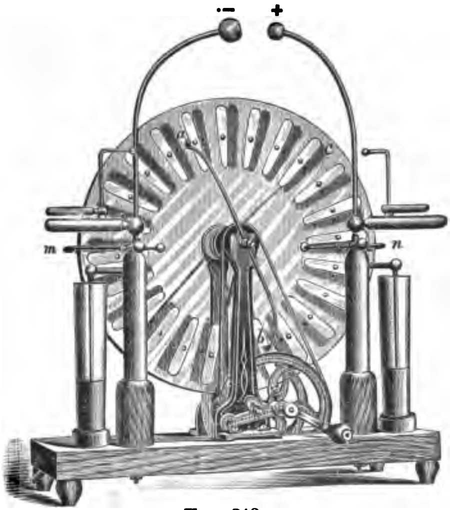

FIG. 243.

The tin-foil strips or carriers on the rear plate of a Wimshurst machine are represented in Fig. 244 by the outer row of strips; those on the front plate, by the inner row. The diagonal conductor that faces the rear plate is represented by *cd*; the one that faces the front plate, by *ab*. The strips from which the arrows proceed are charged positively; the others, negatively. The strips at the top of the rear plate are represented in the diagram as being positively charged; those at the bottom as being negatively charged. These conditions are reversed for the front plate. The maximum charge upon one of the tin-foil strips or carriers is represented as six units. The opposite motions of the two plates are represented by the two large curved arrows. As the carrier *a* moves into the position shown in the diagram, it comes under the inductive influence of the posi-

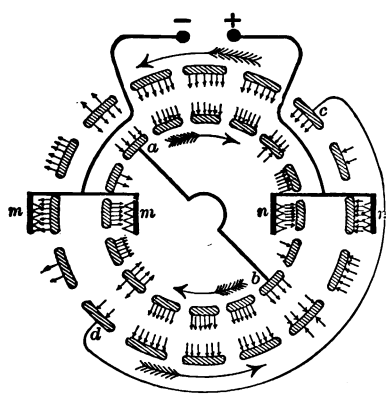

FIG. 244.

tively charged carrier opposite it on the rear plate. At this instant, it touches the brush of the diagonal conductor, and a transfer of positive electrification from *a* to *b* leaves the carrier at *a* negatively charged. At the same instant and in the same way, the carrier at *b* is positively charged. Similar effects are also produced in the carriers at *c* and *d*. Thus, the carriers of both plates come to *m* and *n*, the combs of the discharging circuit, similarly charged, positively at *n*, and negatively at *m*. The inductive action of these carriers upon the discharging circuit electrifies its two sides oppositely.

High Voltage Currents.

Experiment 220. — Wind several turns of wire upon a piece of glass tubing inside of which is an unmagnetized sewing-needle. Discharge a Leyden jar through the wire, and test the needle to see if it has been magnetized.

Experiment 221. — Wind ten or more turns of insulated wire, No. 22, on the outside of a thin glass tumbler, being careful that the turns do not touch each other. A coating of shellac varnish will help to hold the wire in place. Wind a smaller coil of ten or twelve turns of similar wire, bringing one end of the wire up through the coil, and being careful that it does not touch any of the convolutions. Tip the two ends of this wire with bullets, and adjust them so that they will be within about 1 cm. of each other. Place the second coil in the tumbler, as shown in Fig. 245, and fill the tumbler with high-grade kerosene. Connect *n*, the lower end of the outer wire, with the tin pan of the electrophorus. Charge the disk of the electrophorus, and discharge it through *m*, the upper end of the outer coil. *Notice the spark between the terminals of the inner coil.* Support an iron rod inside the inner coil, being careful that it does not touch the wire. Repeat the experiment, and notice

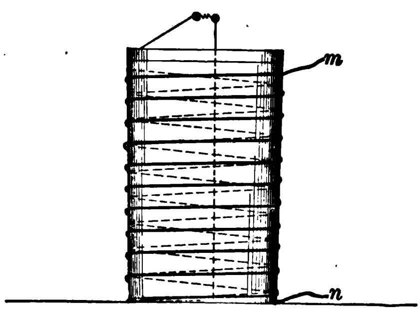

FIG. 245.

that the "striking distance" between the terminals of the inner coil may be increased.

Experiment 222. — Connect one terminal of the outer coil of the apparatus used in Experiment 221 to a terminal of the secondary of an induction coil. Set the latter in operation, and discharge the other terminal of its secondary into the other terminal of the outer coil of the tumbler. Notice the series of sparks between the terminals of the inner coil of the tumbler, and that the sparks there keep step with those of the induction coil.

316. Identity. — The experiments just given indicate the remarkable similarity between current electricity at high voltage, and static electricity. Many facts tend inevitably to the conclusion that *the two kinds of electricity are identical.*

317. Geissler and Crookes Tubes. — A Geissler tube consists of a closed glass vessel with platinum electrodes sealed into the glass, so that an electric discharge from an induction coil may be produced in a rarefied gas within the vessel. (See Fig. 249.) The rarefaction is about one two-hundredth of an atmosphere. The discharge produces a beautifully stratified light, the color of which depends upon the nature of the contained gas. If the exhaustion of the tube is continued to one-millionth of an atmosphere or beyond, the phenomena exhibited differ from those of ordinary gases as much as those of gases differ from those of solids or liquids. The tube is then called a *Crookes tube.*

Nature of Electric Discharge.

Experiment 223. — Let another pupil push a pin through a visiting card. Examine the card, and try to tell from which side of the card the perforation was made. Perforate the card by the spark of an induction coil, examine it carefully, and try to tell from which side the perforation was made. Similarly examine the perforations made in a card by the discharges of an electric machine, and of a Leyden jar. What do you infer from your comparison of the perforations?

Experiment 224. — Wind two or three layers of paper upon *MN* (Fig. 246), a bar of soft iron, and about fifty turns of No. 22 insulated copper wire upon the paper. Twist loops in the wire at *A* and *B*. Tip the ends of the wire with bullets, and bring them very near each other, as at *C*. Ground the wire at *B*, i.e., put it into electrical connection with the earth, and discharge the electrophorus or a Leyden jar into the loop at *A*. Notice the sparks at *C*.

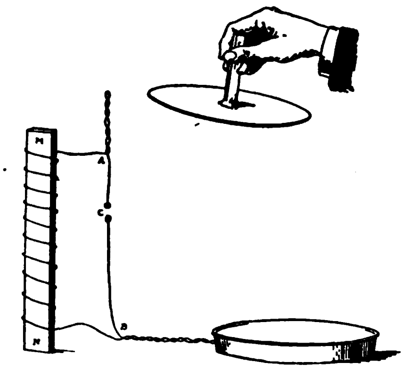

FIG. 246.

Experiment 225. — Straighten the wire of Experiment 224, and bend it into a long loop returning on itself as in Fig. 247. Adjust the knob terminals at *c* for the same distance as in Experiment 224. Ground *b*, and discharge the electrophorus or Leyden jar into *a*, as before. You will find great difficulty in getting a spark at *c*, and may not be able to do so at all.

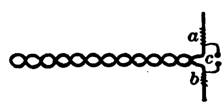

FIG. 247.

318. Oscillatory Discharge. — Recent investigations have done much to justify the statement that *in an electric discharge the flow surges back and forth thousands of times in the brief interval measured by the duration of the spark.*

(*a*) The sparks between the knobs, as observed in Experiment 224, show that, for some reason, the electricity preferred the path through the air at *C*, with a resistance of millions of ohms, to the path through the wire coiled upon *MN*, with a resistance of only a small part of an ohm. If the flow was of the nature of a direct current, it would have passed in the greatest quantity through the path of least resistance. On the other hand, if the flow was that of an alternating current, it would be governed by the law given in § 310 (*c*), rather than by Ohm's law. The experiments just given indicate that the paradoxical choice of path was due to the impedance of the wire coiled around the iron bar *MN*. Study of the mathematical expression for impe-

dance shows that the factor *n* is the only one that is great enough to account for the very great impedance noticed, and that it must represent a frequency of alternation measured by hundreds of thousands.

319. Atmospheric Electricity.—The surface of the earth is electrified. The electrical density varies greatly at different times and places. The origin of this electrification is not known with certainty. The clouds collect and concentrate the diffused electrification of the atmosphere.

(*a*) Suppose a thousand spherical watery particles, each having a unit charge, to coalesce to form a water-drop. The diameter of this drop will be ten times that of a single particle, its electric capacity will be ten times as great, but its charge will be a thousand times as great; in other words, its potential will be increased a hundred fold. *The condensation and aggregation of charged vapor particles must result in the production of a very high potential.*

320. A Lightning Flash is simply a disruptive discharge between two surfaces oppositely and highly electrified. The discharge may be from cloud to cloud, or from cloud to earth. Like the discharge of the Leyden jar, the lightning flash is oscillatory. A lightning flash a kilometer long corresponds to a difference of potential of about thirteen million electrostatic units.

(*a*) The induced charge on the earth tends to accumulate on buildings, trees, and other elevated objects, thus reducing the thickness of the dielectric, intensifying the attraction between the opposite electrifications, and increasing the liability of such elevated bodies.

(*b*) The sound that follows a lightning flash constitutes *thunder*. The sudden expansion and compression of the heated air along the line of discharge is followed by a violent rush of air into the partial vacuum produced, thus causing the sound. One-fifth the number of seconds that intervene between seeing the flash and hearing the roar approximately indicates the number of miles that the observer is from the discharge.

Thermo-electricity.

Experiment 226. — Twist together, end to end, an iron and a German-silver wire, and attach their free ends to the terminals of a galvano-

scope. Heat the junction of the two wires. The deflection of the needle indicates that an electric current was generated. Cool the junction of the dissimilar metals with ice. The opposite deflection of the needle shows that the current now generated flows in the opposite direction.

321. Thermo-electric Pile. — Two dissimilar metals joined and used as in Experiment 226 constitute a *thermo-electric pair.* Antimony and bismuth are the metals generally used for the purpose. Many such pairs connected in series and having their ends exposed constitute a *thermo-electric pile.* Such a pile with conical reflectors is represented in Fig. 248. When its terminals are connected to the terminals of a delicate galvanoscope, the combination constitutes a *thermoscope* of great sensitiveness.

FIG. 248.

EXERCISES.

1. Describe the electrophorus.
2. Explain the action of the electrophorus.
3. Sketch the connections of the induction coil. Explain the action of the automatic current interrupter.
4. Attach a Geissler tube (Fig. 249) to the secondary terminals of an induction coil. Put the coil in operation, and notice the discharge through the tube, and the difference from its discharge through air. Measure the maximum length of the spark obtainable with the coil, and compare it with the length of the longest discharge that you can get through a Geissler tube.

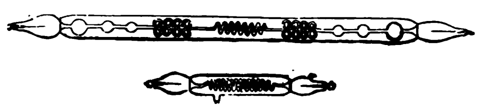

FIG. 249.

Present a magnet pole to the Geissler tube, and notice the deflection

of the discharge. Reverse the polarity of the primary of the induction coil. Notice that the discharge is now deflected in an opposite direction. Study the discharge through the tube with reference to the different appearances of the two ends of the tube. Reverse the coil, and notice the corresponding reversal in the positions of the violet tint and the scintillations. If you have no induction coil, use the Wimshurst machine.

5. Suspend a tin plate about 10 cm. square from each binding-post of the secondary of a strong induction coil, as shown in Fig. 250. Let the plates hang parallel to each other and about 8 cm. apart. Start the coil. Darken the room, and hold a small Geissler tube in the electrostatic field of force between the plates, with the ends of the tube near but not touching them. The tube glows brightly. Touch the plates with the ends of the tube. Notice the increased brightness. Quickly lay the tube in a dark corner, and notice the after-glow.

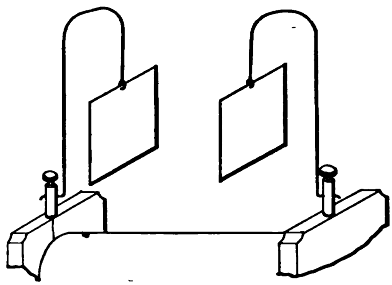

FIG. 250.

6. Grasp a 110-volt incandescence lamp firmly in the hand, keeping the fingers away from the brass cap. Let some one else charge the lamp with an electrophorus. Discharge the lamp by touching the brass cap, keeping an eye on the filament. When the discharge takes place, the filament swings around the bulb as if it were sweeping off the charge from the surface of the glass and delivering it to the cap. As there is danger of breaking the filament, it is well to use an old lamp. Repeat the experiment in the dark, and notice the brilliant glow of the lamp when discharging.

7. Connect the outside coating of a Leyden jar by a wire to one of the terminals of an induction coil. Bring the knob of the jar near the other terminal of the coil and allow sparks to pass between them for a minute. Remove the jar, and connect its two coatings with the fingers. A smart shock shows that the jar is charged. Bring the knob of the jar into contact with the free terminal of the coil instead of allowing the discharge to spark across. It will be found impossible thus to charge the jar.

8. Support two metal balls, *a* and *b*, between the terminals of an induction coil, put the coil in operation, and determine the limiting length of the discharge between the balls. Then connect a Leyden jar to the terminals, as shown in Fig. 251. Start the coil again, and notice that the spark will not strike across so long a gap, but that it is a much hotter, "fatter" spark. Open the circuit at *x*, and insert the oil transformer used in Experiment 221. It will be found to work in a satisfactory manner.

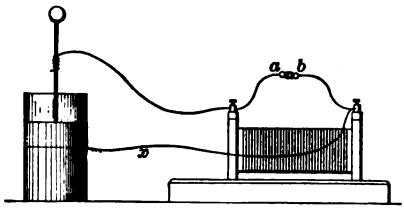

FIG. 251.

III. ELECTRICAL MEASUREMENTS.

322. Electrical Units. — The practical, electromagnetic units in common use among electricians are derived as multiples and submultiples of the absolute, C.G.S. electrostatic units.

(*a*) The wonderful advance made in the last few years by electrical science is largely due to the adoption of definite electrical units, and the general practice of making exact electrical measurements.

323. The Galvanometer *is an instrument for determining the strength of an electric current* by means of the deflection of a magnetic needle around which the current flows. When a galvanoscope is provided with a scale so that the deflections of its needle may be measured, it becomes a galvanometer.

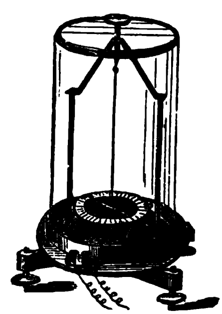
FIG. 252.

(*a*) The *astatic galvanometer* consists of an astatic needle supported by an untwisted fiber so that one of its needles is nearly in the center of the coil through which the current passes while the other needle is just above the coil. *When the deflections of the needle are less than* 10°

or 15°, *they are very nearly proportional to the strengths of the currents that produce them.* A current that deflects the needle 6° is about three times as strong as one that deflects it 2°.

(*b*) The *tangent galvanometer* consists of a very short magnetic needle suspended so as to turn in a horizontal plane, and with its point of support at the center of a vertical hoop or coil of copper wire through which the current is passed. In use, the hoop is placed in the plane of the magnetic meridian, the current that is to be measured is sent through the hoop, and the deflection of the needle is read from the scale. The strength of the current is proportional to the tangent of the angle of deflection. The values of such tangents may be obtained from a table of natural tangents. Such a table is given in the appendix.

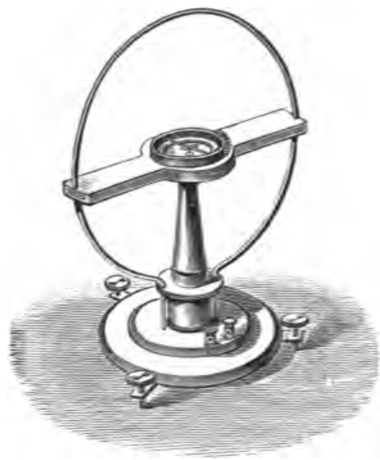

FIG. 253.

(*c*) Any sensitive galvanometer, the needle of which is directed by the earth's magnetism, and in which the frame on which the coils are wound is capable of being turned round a vertical axis, may be used as a *sine galvanometer.* The coils are set parallel to the needle (i.e., in the magnetic meridian). The current is then sent through the coils, deflecting the needle. The coil is then turned until it overtakes the needle, which once more lies parallel to the coil. *The strength of the current is proportional to the sine of the angle through which the coil has been turned.* The values of the sines may be obtained from a table of natural sines. Such a table is given in the appendix.

(*d*) The *mirror galvanometer* has a very short needle rigidly attached to a small concave mirror that is suspended by a delicate fiber in the center of a vertical coil of small diameter. A beam of light from a lamp passes through a small opening under a millimeter scale about a meter from the mirror, falls upon the mirror, and is reflected back upon the scale. A current passing through the coil turns the needle

and its mirror, thus shifting the spot of light to the right or left. The apparatus was devised for use with the Atlantic cable, and is exceedingly sensitive. The current produced by dipping the point of a brass pin and the point of a steel needle into a drop of salt water, and closing the external circuit through this instrument, sends the spot of light swinging way across the scale.

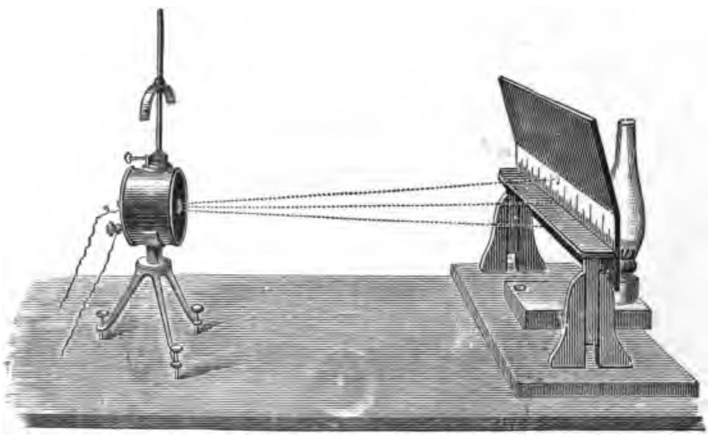

FIG. 254.

(*e*) A galvanometer of low resistance, graduated for the direct measurement of electric currents and giving its readings in amperes, is called an *ammeter*. Any galvanometer that is wound with wire of sufficient size safely to carry the current to be measured, and properly graduated, may be used as an ammeter.

(*f*) If a galvanometer is put in a shunt circuit between two points of different potentials, current will pass through it, and the current thus passing may be used to measure the difference of potential. A galvanometer of high resistance, graduated so as to indicate in volts the difference of potential between its terminals, is called a *voltmeter*.

(*g*) A specially constructed galvanometer is sometimes used to measure, in watts, the rate of working, or the electrical activity of the current. Such a device is called a *wattmeter*. Electric current being a merchantable commodity, it is often desirable to measure both the

rate at which the electrical energy is delivered and the time during which it is delivered, i.e., the number of watt-hours. This is accomplished by a modification of the wattmeter. The current swings an armature coil with complete revolutions in the field of a stationary coil. These revolutions are counted by a registering apparatus that gives direct readings in watt-hours.

(*h*) The resistance of a galvanometer should correspond to that of the rest of the circuit; i.e., a high resistance galvanometer should be used on a high resistance circuit, and vice versa.

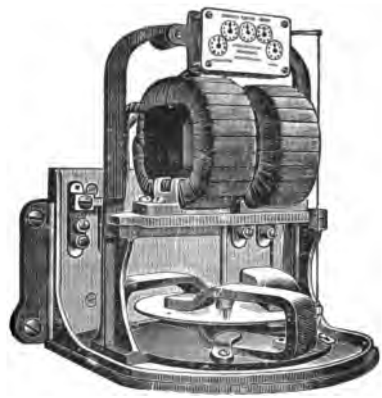

FIG. 255.

324. Resistance Coils are made of wires of known resistance for use with galvanometers in measuring resistances. Insulated and doubled wires are wound upon spools, and the terminals of each spool connected to heavy brass blocks, *A*, *B*, *C*, etc., on the top of the box that carries the spools. This style of winding destroys the magnetic effects, and reduces the self-induction of the coils.

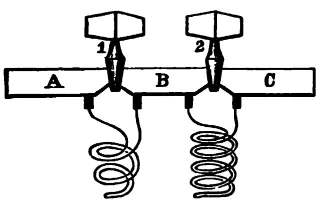

FIG. 256.

(*a*) When the brass plugs are inserted as shown in Fig. 256, the coils are short-circuited, but when a plug is withdrawn the current

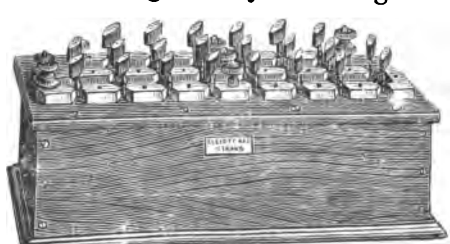

FIG. 257.

passes through the corresponding coil. Such coils with resistances of 1, 2, 2, 5, 10, 10, 20, 50, 100, 100, 200, 500 ohms, etc., severally are connected to form a resistance-box as shown in Fig. 257. By withdrawing the proper plugs, one may throw into the circuit any resistance desired, from a single ohm up to the full capacity of the box.

325. The Measurement of Resistance is made in several ways according to the nature and magnitude of the resistance. Much use is made of the following important principle: *The fall of potential between two points on a conductor is proportional to the resistance of the conductor between those points.*

(*a*) We may observe a certain deflection of the galvanoscope with a wire of unknown resistance in the circuit. By removing such unknown resistance, and inserting known resistances until an equal deflection of the same galvanoscope with the same cell is obtained, we may determine the resistance of the wire first used. This method is called resistance measurement by *substitution.*

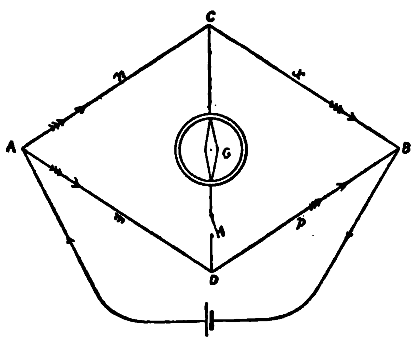

FIG. 258.

(*b*) The method that has the most general application is that known as the *Wheatstone bridge.* In Fig. 258, we have a quadrangle of resistances. The four conductors, m, n, p, and x, that form the sides are called the arms; the conductor that joins C and D and carries the galvanometer, G, is called the bridge. The current divides at A, and reunites at B. The fall of potential through n and x is evidently the same as the fall through m and p. The resistances of the arms may be so adjusted that, when the bridge-circuit is closed at K, there will be no deflection of the needle of G. Under such circumstances, C and D are at the same potential, and it may be shown that the resistances of the four arms "balance" by being in proportion, thus: —

$$m : n :: p : x.$$

When three of these resistances are known, the other one may be calculated.

(*c*) The best way of determining the internal resistance of a voltaic cell is to join two similar cells in opposition to each other, so that they send no current of their own. Then measure their united resistance (as if it were the resistance of a wire), as just described. The resistance of one cell will be half that of the two.

326. The Measurement of E.M.F., or of difference of potential, is generally made with a volt-meter, or by comparison with the E.M.F. of a standard cell.

EXERCISES.

1. A volt-meter that has a resistance of 26,000 ohms indicates 37 volts. (*a*) What is the strength of the current? (*b*) What voltage would such an instrument indicate with a current of 3 milliamperes?

2. Two volt-meters, one of which has a resistance of 25,000 ohms, and the other a resistance of 15,000 ohms, are connected in series across 110 volts. (*a*) What current flows through the system? (*b*) What voltage does the first instrument indicate? (*c*) The second instrument?

Ans. (*a*) 0.00275 ampere; (*b*) 68.75 volts; (*c*) 41.25 volts.

3. How many watts are taken by a station volt-meter that indicates 110 volts and uses a 0.002-ampere current?

4. A dynamo is run at 450 revolutions, developing a current of 9.925 amperes. This current deflects the needle of a tangent galvanometer 60°. When the speed of the dynamo is sufficiently increased, the galvanometer shows a deflection of 74°. What is the current developed at the higher speed? *Ans.* 20 amperes.

5. Solder one end of a piece of No. 20 insulated copper wire, 50 cm. long, to one end of a piece of zinc $10 \times 2.5 \times 0.5$ cm., and amalgamate the zinc. Solder a similar wire to a piece of sheet copper 10×10 cm. Put the zinc into a porous cup 4 or 5 cm. in diameter and 10 cm. deep, and fill the cup to the depth of 8 cm. with dilute sulphuric acid. Put the copper plate into a glass vessel 7 or 8 cm. in diameter and 10 cm. deep, bending it slightly to fit the inner surface of the tumbler. Put the porous cup and its contents into the glass vessel, and fill the latter to the depth of 8 cm. with a saturated solution of copper sulphate. Connect the terminals of this Daniell cell with the terminals of a low resistance galvanoscope, and record, at intervals of 5 minutes for half

an hour, the deflections of the needle. Ascertain whether the current strength is practically constant after the porous cup is wet through.

6. To a table-top or other board, tack two stout metal strips, AC and BD, with a meter stick between them, as shown in Fig. 259. Tack a similar metal strip, EF, 90 cm. long, in position as shown. Solder metal binding-posts at the ends of these strips, and at the middle of EF. The resistance of the strips is so small that it need not be considered. Tightly stretch a German-silver wire, No. 26, over the face of the meter stick, and solder it to the faces of the metal strips at r and s. One of the terminals of a sensitive galvanoscope is to be connected to EF; the other galvanoscope wire is to make a

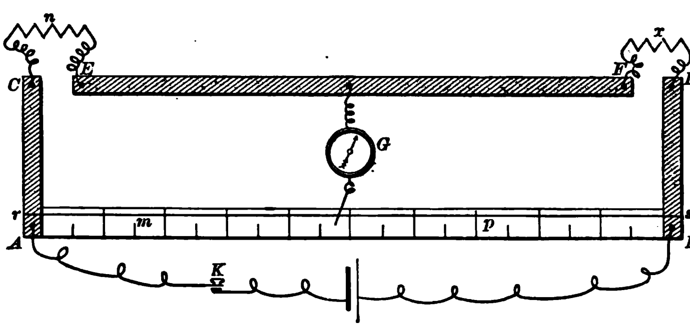

FIG. 259.

sliding contact with the German-silver wire, dividing it into two variable parts, m and p. Put the apparatus into the circuit of a voltaic cell, as shown in the figure. Interpose a conductor of unknown resistance at x and a known resistance of approximately equal value at n (the better this guess at the equality of resistances, the less the liability of error in the results attained). You have a Wheatstone bridge, easily comparable to that shown in Fig. 258. Make the sliding contact at a point on rs that causes a deflection to the right, and note its position on the meter scale; find a position that causes a deflection to the left. As the point of contact at which the bridge will balance is between these points, it is easy to locate it definitely. When the contact is made at such a point on rs that there is no deflection of the needle, read the values of m and p directly from the meter scale, and determine the resistance of x. Repeat the work with

two slightly different values for n, and take the average of the three computed values of x.

NOTE. — In practice, the galvanoscope should be placed at a distance from the rest of the apparatus, the connecting wires being kept near together.

IV. SOME APPLICATIONS OF ELECTRICITY.

Incandescence Lighting.

Experiment 227. — Place a few centimeters of No. 36 platinum wire across the terminals of a battery of several bichromate cells in series. The wire will be heated to incandescence, and may be melted. Lift one of the plates partly from the liquid, and notice the diminished brilliancy of the light emitted by the incandescent wire. By gradually lowering the plate into the liquid as the cells weaken, the brilliancy of the platinum wire may be kept nearly uniform. Notice the progressive oxidation of the wire. Try to continue the experiment until the wire breaks down by oxidation, noting the length of time taken. Repeat the work with No. 36 iron wire, and compare the lasting qualities of the two wires.

327. Incandescence Lamps operate essentially on the principle illustrated in Experiment 227, the current being sent through some substance that, because of its high resistance, becomes intensely heated and brilliantly incandescent. The only suitable substance known for such a resistance is a carbon filament, which is enclosed in a glass bulb from which the air is exhausted to prevent combustion. The ends of the carbon filament are cemented to short platinum leading-in wires that are embedded in the glass by the fusion of the latter.

FIG. 260.

(*a*) As incandescence lamps are generally connected in parallel, they require a heavy current at a comparatively low voltage. Such currents require large conductors that are generally made of copper. With lamps placed in parallel, the greater the number of lamps in use,

the less the resistance of the circuit. The current is usually operated at 110 volts, and each 16-c.p. lamp takes about 0.5 of an ampere. The expenditure is, therefore, nearly 3.5 watts per candle-power.

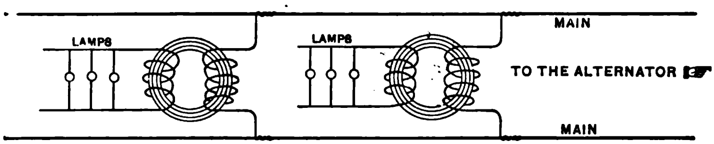

FIG. 261.

(*b*) Incandescence lamps are often placed on the secondary circuit of a "step-down" transformer, the primary circuit of which carries the high-voltage current of an alternator. The primary coils of several transformers may be put in series, or in multiple arc, as shown in Fig. 261.

CAUTION.—In experimenting with an incandescence electric lighting current, remember that a low resistance placed across the mains will receive an enormous current. Many a galvanoscope and other piece of apparatus has been ruined in this way. Never "ground" an electric lighting wire.

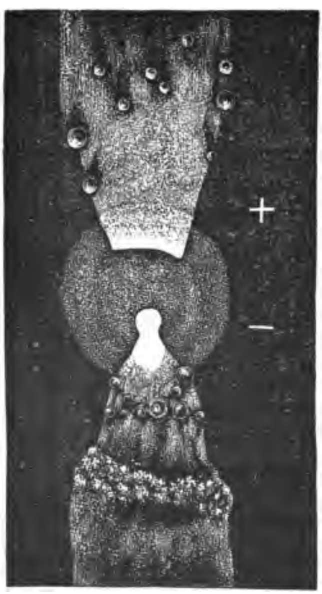

FIG. 262.

328. The Voltaic Arc is the most brilliant luminous effect of an electric current. When carbon rods that form part of the circuit of a strong electric current are separated, *their tips glow with a brilliancy greater than that of any other light under human control, and the temperature of the intervening arc is unequaled by that of any other source of artificial heat.*

(*a*) When the carbons are sepa-

rated, the intervening layer of vaporized carbon becomes a conductor of very high resistance. The intense heat of the arc is due to the conversion of the energy of the current and not to combustion; the arc may be produced in a vacuum where there could be no combustion. The general appearance of the arc is shown in the accompanying figure. Most of the light is radiated from the concave tip of the positive carbon. The arc may be studied by projecting its image on a screen, or by looking at it through a piece of smoked glass or through several thicknesses of colored glass.

329. The Arc Lamp is essentially a device for automatically separating the carbons when the current is turned on, for "feeding" the carbons together as they are burned away at their tips, and, in some cases, for short-circuiting the lamp in case of irregularity or accident.

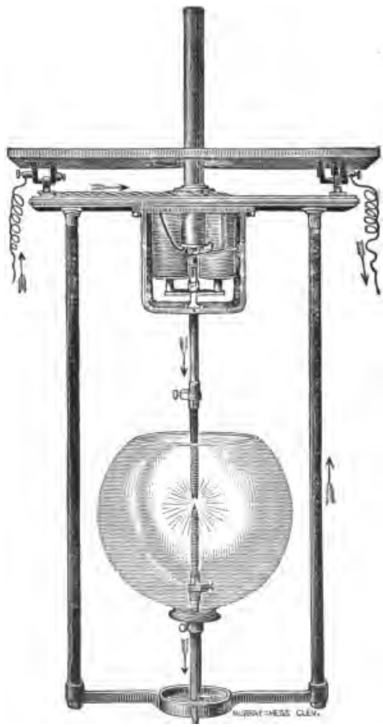

FIG. 263.

(*a*) Such lamps of from one to two thousand candle-power require a current of from 7 to 10 amperes, and have a potential difference between the carbons of 45 to 50 volts. They are generally operated in series, so that the current passes in succession through all the lamps on the circuit. As many as 125 such lamps have been thus worked on a single circuit.

Electric Motors.

Experiment 228. — Connect a small battery-motor (one may be bought for a dollar or less) to a number of cells joined in series, and interpose a low resistance galvanoscope as indicated in Fig. 264. Hold the shaft of the motor to prevent its rotation, and note the reading of the galvanoscope. Then permit the motor shaft to revolve, and again note the reading of the galvanoscope. The resistance of the circuit seems to be greater when the armature is in motion than when it is at rest. Dynamos and motors are often represented by commutator circles and brushes, as in Fig. 264.

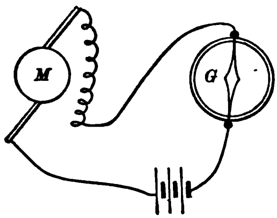

FIG. 264.

330. An Electric Motor *is a device for doing mechanical work at the expense of electric energy.* As made for industrial use, it is generally similar to a dynamo in form and construction, and is often identical with it.

(*a*) The current from a dynamo is sent through the armature of the motor (the binding-posts of one machine being connected to the binding-posts of the other), and causes the motor armature to revolve in a direction opposite to that in which it would revolve if the motor was acting as a dynamo. Any direct current dynamo will act as an efficient motor when it is supplied with a current of the same strength and potential as that which it yields when acting as a dynamo. The pulley on the armature shaft is belted or geared to other machinery.

(*b*) The convenience, cleanliness, and economy of the electric motor have led to its common use for the operation of light machinery, such as fly and ventilating fans, sewing-machines, lathes, printing-presses, etc. On the larger scale, the motor is used for the propulsion of street cars, and is even displacing the locomotive engine on some railways. As a generator and as a motor, the dynamo is revolutionizing more than one department of the industrial world.

331. An Electric Bell consists mainly of an electromagnet, *E*, and a vibrating armature that carries a hammer, *H*, that strikes a bell. One terminal of the magnet coils is connected to the binding-post, and the other terminal to the

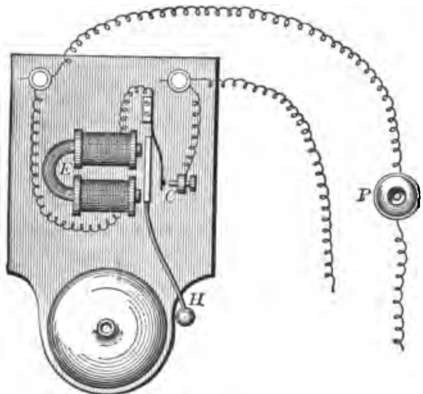

FIG. 265.

flexible support of the armature. The armature carries a spring that rests lightly against the tip of an adjustable screw at *C*. This screw is connected to the other binding-post. The bell is connected to a battery of two or three cells in series, a push-button, *P*, or some other device for closing the circuit being placed in the line.

(*a*) When the circuit is closed by pushing the button at *P*, the magnet attracts the armature and causes the hammer to strike the bell. The continued action of the apparatus is like that of the vibratory interrupter of the induction coil, as explained in § 313 (*b*).

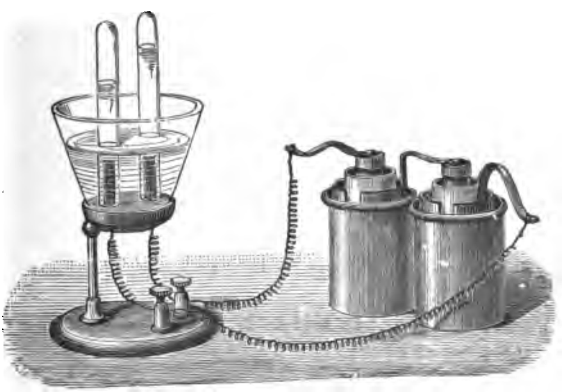

FIG. 266.

Electrolysis.

Experiment 229. — Arrange apparatus as shown in Fig. 266. The glass vessel may be made from a glass funnel, or by cutting the bottom

from a wide-mouthed bottle, and may be supported in any convenient way. The platinum electrodes should be about 2 cm. apart and covered with water (H_2O) to which a little sulphuric acid has been added to increase its conductivity. Fill two test-tubes with acidulated water, and invert them over the electrodes. When the circuit is closed, bubbles of oxygen escape from the positive electrode, and bubbles of hydrogen from the negative. The volume of hydrogen thus collected will be about twice as great as that of the oxygen. When a sufficient quantity of the gases has been collected, they may be tested; the hydrogen, by bringing a lighted match to the mouth of the test-tube, whereupon the hydrogen will burn; the oxygen, by thrusting a splinter with a glowing spark into the test-tube, whereupon the spark will kindle into a flame. If the gases thus separated are mixed, and an electric spark produced in the mixture, the ions will recombine with explosive violence.

332. Electrolysis, etc. — The decomposition of a chemical compound, called the *electrolyte*, into its constituent parts, called *ions*, by an electric current is called *electrolysis*. When, for example, water is electrolyzed, the hydrogen collects at the negative electrode, called the *cathode;* such an ion is called a *cation*, and is said to be *electropositive*. The oxygen similarly collects at the positive electrode, called the *anode;* such an ion is called an *anion*, and is said to be *electronegative*.

(*a*) In battery or in electrolytic bath, the metallic or electropositive ion *is carried with the current* through the electrolyte. Similarly, when a chemical salt is electrolyzed, the metallic base is carried to the cathode, while the acid constituent appears at the anode. The amount of chemical decomposition effected in a given electrolytic bath in a given time is proportional to the current strength. This principle has been utilized in devices for the commercial measurement of electric energy.

Electrometallurgy.

Experiment 230. — Fasten a copper wire to a silver coin, and a similar wire to a piece of sheet copper of about equal size. Suspend the two pieces of metal in a tumbler containing a solution of copper sulphate. Connect the wire that carries the silver to the negative

terminal of a strong battery of cells joined in parallel, and the other wire to the other terminal. Close the circuit, and notice that a firm, hard copper coating is deposited upon the silver. Reverse the current until the copper is removed from the silver. Then connect the cells of the battery in series, and notice that copper is deposited upon the silver as a spongy mass instead of a firm coating.

333. Electrometallurgy is the art or the process of depositing certain metals, such as gold, silver, and copper, from solutions of their compounds by the action of an electric current. Its most important applications are electroplating and electrotyping. Current for such processes is generally provided by specially constructed dynamos of low voltage. Such dynamos are called electroplating machines, or simply *platers*.

Secondary Cells.

Experiment 231. — Arrange apparatus as in Experiment 229. After the passage of the current for a few minutes, disconnect the battery and put a galvanoscope in its place. The deflection of the needle shows that the "water voltameter" is developing an electric current, and illustrating the reversibility of electrolytic action.

334. A Secondary or Storage Battery is a combination of cells each of which consists essentially of two plates of metallic lead coated with red oxide of lead, and immersed in dilute sulphuric acid. When such a cell is "charged" by passing an electric current through it, the electrolysis of the liquid liberates oxygen and hydrogen. One of these ions peroxidizes the coating of one of the plates; the other ion reduces, i.e., deoxidizes, that of the other plate, thus storing up chemical energy to be given back as an electric current when the poles of the charged cell are connected, and the chemical action is reversed. Such a cell or battery is often called an *accumulator*.

(*a*) In a charged secondary battery, the two plates are unlike, and the potential energy of chemical separation is converted into the

kinetic energy of an electric current, just as with an ordinary or "primary" battery. When a secondary battery has run down, the passage of a current through it will restore the plates to their former effective condition; when a primary battery has run down, a current will not thus restore the plates.

(*b*) The condition of the plates of a charged secondary cell is closely analogous to that of the polarized plates of a primary cell. The ions have a tendency to reunite by virtue of their chemical affinity, and thus to set up an opposing E.M.F., as was illustrated in Experiment 231.

Telegraph.

Experiment 232. — Connect two telephone receivers, two batteries, and two keys as shown in Fig. 267. Both batteries are on open

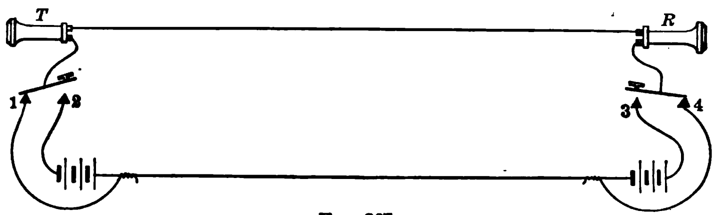

FIG. 267.

circuit. When the key is depressed at 2 or 3, and thus raised at 1 or 4, clicks will be heard at *T* and *R*. Trace the path of the current in each case. It would be easy to devise a code of signals for communication with such apparatus between two distant stations.

Experiment 233. — Support a metal cylinder, *C*, upon an axle. Pivot

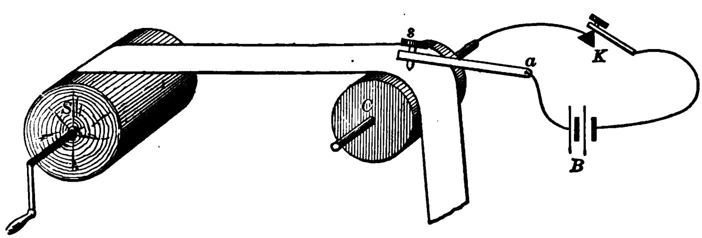

FIG. 268.

a metal bar at *a* (Fig. 268) so that the style, *s*, at its other end may rest upon the cylinder. Connect battery wires to the axle of the

cylinder, and at *a*, and interpose a key, *K*. Make a paste by boiling starch in water. Dissolve about 3 g. of potassium iodide in 3 or 4 cu. cm. of hot water, and add a little of the paste. Prepare a long ribbon of white paper, and soak it in the starch and iodide solution. While the paper is moist, fasten one end of it to a spool, *S*, and turn the handle so as to draw the paper between the style and cylinder. While the paper is moving over the surface of *C*, make and break the circuit at *K* so as to inscribe a series of blue dots and dashes on the paper at *s*. With *K* at one station and *s* at another, it would be easy for a person at *K* to send a dot and dash message to a person at *s*. Consult the code of signals given in § 335, and, with your apparatus, write the word *Morse*.

335. The Electromagnetic Telegraph is a device for transmitting intelligible messages at a distance by means of interrupted electric currents. It consists essentially of a line-wire or main conductor; a battery or dynamo for the generation of the current; a transmitter or key; and an electromagnetic receiving instrument. The system devised by Professor S. F. B. Morse about 1844 is still in general use.

(*a*) The Morse code of signals is as follows:—

Letters, etc.			Figures.
a ·—	*k* —·—	*u* ··—	1 ·——·
b —···	*l* ——	*v* ···—	2 ··—··
c ·· ·	*m* — —	*w* ·——	3 ···—·
d —··	*n* —·	*x* ·—··	4 ····—
e ·	*o* · ·	*y* ·· ··	5 ———
f ·—·	*p* ·····	*z* ··· ·	6 ······
g ——	*q* ··—·	*&* · ···	7 ——··
h ····	*r* · ··	, ·—·—	8 —····
i ··	*s* ···	? —··—·	9 —··—
j —·—·	*t* —	. ··——··	0 ———

To prevent confusion, a small space is left between successive letters, a longer one between words, and a still longer one between sentences, thus:—

```
 H e    w   i  l  l     c  o    m  e    a  t    t  e  n     .
.... ·  ·—— ·· —— ——   ·· · · ·  —— ·   ·— —    — · —·    ··——··
```

(*b*) A carefully insulated wire connects the apparatus at the several stations. When the stations are far distant from each other, the ends of the line-wire are connected to large metallic plates buried in the earth (see Fig. 273), or otherwise "grounded." The current generator generally consists of a dynamo, or of many gravity cells connected in series. The transmitter or key (Fig. 269) is manipulated by the operator for making and breaking the current at will. When it is not in use, the circuit is closed at that station by the switch, *s*. In the early days of telegraphy, a dot and dash record of the signals sent by the operator at the key was made by a *register* at the receiving station. The principle of this instrument is illustrated in Experiment 233. Such registers are little used nowadays, most operators reading by sound, i.e., determining the message from the clicks of a *sounder*, as will soon be explained.

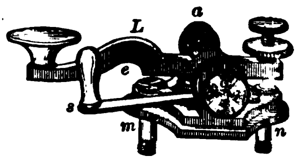

FIG. 269.

(*c*) In the Morse system, just described, a given wire can transmit only one message at a time. By what is known as the *duplex system*, a wire may be made to convey two messages, one each way, at the same time, without conflict. By what is known as the *quadruplex system*, a wire may be made to carry four messages, two each way, at the same time. The *multiplex system* enables the sending of six or more messages in the same direction at one time. In the so-called *rapid system*, the message is first prepared by punching a series of holes in a strip of paper, each perforation or group of perforations representing a letter. This strip of paper is rapidly passed under metal points connected with the line-wire. At each perforation, a point passes through the paper and closes the circuit. At the other end of the line, a band of chemically prepared paper is drawn rapidly under a style connected with the line-wire. The current that is interrupted at the sending station makes a series of stains on the prepared paper at the receiving station, as is illustrated in Experiment 233. As the transmission and recording are automatic, the messages may be sent in rapid succession. There are several telegraphic-printing systems, the object of which is to print the message directly upon paper as it is received. *Facsimile telegraphy* has also been accomplished. In *submarine telegraphy*, the transmitted signals are made visible by a mirror galvanoscope (§ 323, *d*) used as a receiver.

The Sounder.

Experiment 234. — Put a key and the apparatus shown in Fig. 236 in series in the circuit of a voltaic cell. Keeping the Morse alphabet in mind, try to signal the word similarly used in Experiment 233. Consider a short interval between two clicks to be a dot, and a longer interval to be a dash.

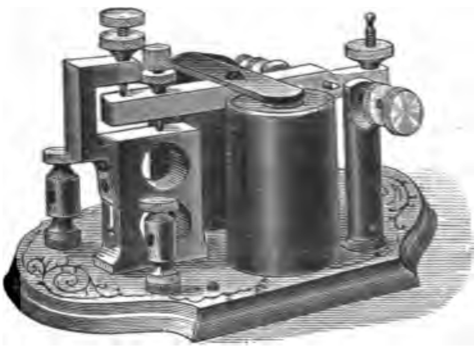

FIG. 270.

336. The Sounder is a telegraphic receiver consisting of an electromagnet, and a pivoted armature that plays up and down between its stops as the circuit is alternately made and broken. The message is "read by sound," i.e., from the clicks made by the armature.

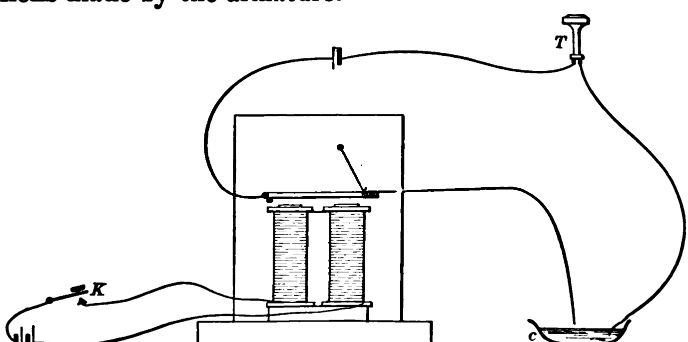

FIG. 271.

The Relay.

Experiment 235. — Fasten a wire to the apparatus used in Experiment 234, so that when the armature descends, the free end of the

wire will be dipped into mercury in the cup at *c*. Arrange apparatus as shown in Fig. 271, placing a sounder or a telephone receiver at *T*. As the key is worked at *K*, the secondary or "local" circuit is made and broken at *c*, and clicks are produced by the instrument at *T*.

337. The Relay. — With a long main line and many instruments in circuit, the resistance may be so great as to render the main-battery current so feeble that it cannot operate the sounder with sufficient energy to render the signals distinctly audible. This difficulty is met by introducing a "local battery" and a "relay" at each station on the line. The relay is an electromagnet made of many turns of fine wire of which the terminals, *a* and *b*, are connected with the main line. This magnet operates an armature lever, *e*, the end of which strikes against a metal contact-piece and thus closes the local circuit through the terminals, *c* and *d*. The "Western Union" standard relay has a resistance of 150 ohms.

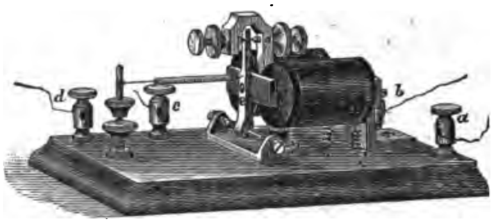

FIG. 272.

(*a*) The arrangement of instruments is best studied at a telegraph station, one or more of which may be found at almost any town or railway station. The general features of the "plant" are represented by the diagram shown in Fig. 273. The pupil will probably find the key, sounder, and relay on a table, and the local battery, *b*, under the table. The keys being habitually closed, the current passes through all relays on the line, the current being continuous except when a message is being sent from some office. When an operator, in sending a message, opens his key, the breaking of the circuit demagnetizes the relays, and allows their springs to draw back the armature levers, *e*. This breaks each local circuit, and demagnetizes each sounder, the spring of which raises its armature. Things are

now as shown in the diagram, which also represents the condition of affairs at every other station on the line. When a message is sent from any station, each relay lever, *e*, acts as a key to its local circuit, it and the sounder armature working in correspondence with the motions of the key at the sending station. Of course, the message may be read from any sounder on the line.

(*b*) If the local circuit at New York (see Fig. 273) is lengthened so as to reach thence to Boston, and the local battery, *b*, is increased to the size of a main battery, *B* (ground connections being made, of course), the relay at New York will transmit to Boston the message received from Cleveland. In such cases, the relay at New York becomes a *repeater*.

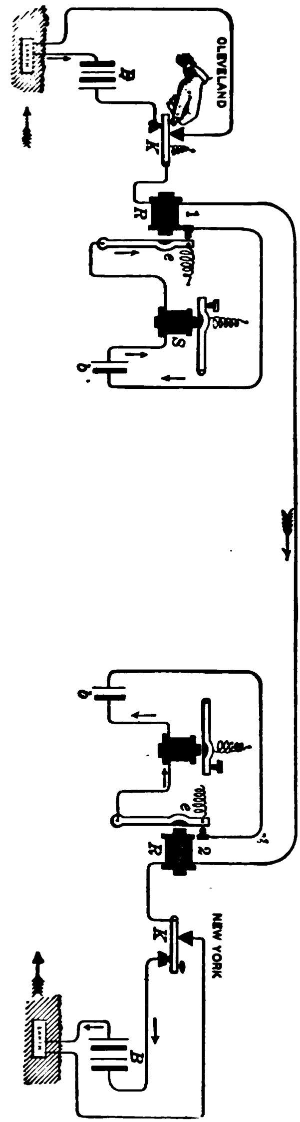

FIG. 273.

The Microphone.

Experiment 236. — Put a telephone receiver in circuit with a battery and two electric-light carbon pencils, as shown in Fig. 274. Vary the resistance of the circuit by pressing the points of the pencils together, and notice the harsh, grating sound heard in the telephone.

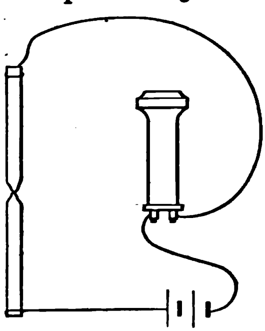

FIG. 274.

338. The Microphone *is an instrument for augmenting small sounds.* Its action is based on the fact that when substances of low conductivity are placed in an electric circuit, the resistance of the circuit is diminished by even a very small pressure.

339. The Telephone *is an instrument for the transmission of articulate speech to a distant point by the agency of electric currents.*

(*a*) The Bell telephone receiver (see Fig. 226) is a magneto-electric device, and is represented in section by Fig. 275. *A* is a permanent bar magnet around one end of which is wound a coil, *B*, of carefully insulated fine copper wire. The terminals of *B* are connected to the binding-posts at *D*. A soft, flexible sheet-iron disk or diaphragm, *E*, is held by a conical mouthpiece or ear trumpet across the face of *B*, near to but not quite touching the end of *A*.

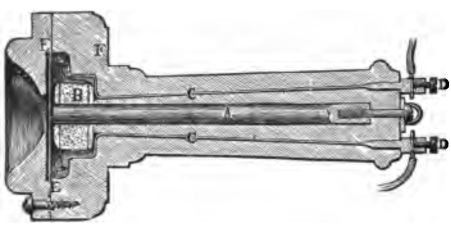

FIG. 275.

(*b*) When a person speaks into the mouthpiece, the sound waves beat upon the diaphragm and cause it to vibrate. Each vibration of the diaphragm modifies the magnetic circuit of the receiver, varying the lines of force that pass through *B*, and thus generating electric pulses in the wire when the circuit is closed. When *E* approaches *B*, a current flows in one direction; when *E* moves the other way, the current flows in the opposite direction.

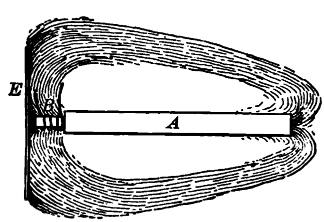

FIG. 276.

(*c*) The currents generated as just described may be sent through a similar instrument, at a considerable distance. As in the case of the telegraph, the earth may form a part of the circuit, but a return wire or complete metallic circuit is

preferable. One of the instruments is used as a transmitter and the other as a receiver. The sound thus produced is feeble, but, when the receiving instrument is held close to the ear of the listener, the sound is clear, and the articulation remarkably distinct. Conversation may be carried on between moderately distant stations with this apparatus, no battery being necessary.

340. The Transmitter *is a microphone adapted for the transmission of telephonic messages* and, in general practice, is so used.

(*a*) In the Blake transmitter, a diaphragm is supported back of a mouthpiece, as in the Bell telephone. Back of the center of the diaphragm is the point of a spring, *m*, that carries a small platinum

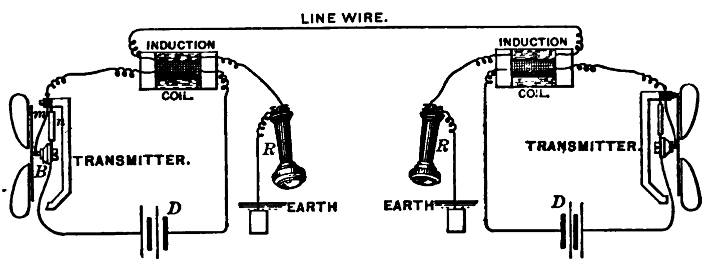

FIG. 277.

ball that makes gentle contact with the diaphragm. Back of this is a spring, *n*, that is insulated from *m*, and that carries a carbon button, *B*, that rests lightly against the platinum ball. The ball, the button, and the primary of an induction coil are put in series in the circuit of a voltaic battery, *D*, as shown in Fig. 277. The variations in the resistance of this circuit, caused by the varying pressure and surface contact between the platinum and the carbon, cause variations in the current that flows through the primary of the induction coil, and thus induce currents in the secondary of the coil. These currents thus induced flow along the line-wire to the receiver at the other station, the connections being as shown in Fig. 277. Complete metallic circuits are preferable to earth connections, and are coming into general use. An electric bell is placed at each station. It is rung by a small magneto at the sending station for the purpose of "calling up" the person at the other station. When the receiver, *B*, is lifted

from the hook that carries it, as shown in Fig. 278, the upward motion of the hook cuts the magneto and the bells from the circuit, and completes the connections substantially as shown in Fig. 277.

FIG. 278.

(*b*) The long distance transmitter, represented in Fig. 278, differs from the Blake transmitter chiefly in the use of a carbon that is granular instead of hard, and in the use of two or three cells instead of one.

(*c*) In most cities and villages, the telephones are connected by wires with a central station, called a telephone exchange. Upon request by telephone, the attendant at the central station connects the line from any instrument with that running to any other instrument. Long distance telephony has been so nearly perfected that it is common to carry on conversation between places as far distant as Boston or New York and Chicago.

341. A Lightning Rod is a metallic conductor placed on a building as a protection from lightning. Its upper end should have several branches terminating in sharp points that are plated, or otherwise protected from rust or corrosion; it should be continuous and run to earth by the most direct path, avoiding sharp bends, and going deep enough to be sure of a good connection with a stratum that is always moist. Iron is as good as copper, and extent of surface is of more importance than sectional area.

(*a*) When an electrified cloud floats over a building, the latter is oppositely electrified by induction. The electrification of the building

escapes from the pointed conductor, and tends to neutralize the electrification of the cloud. Its action may proceed too slowly to keep down the rapidly rising potential of the cloud and to prevent the disruptive discharge, but even then the rod tends to protect the building by offering a path of less resistance. The discharge does not always follow the path of least resistance, but the protection is probable. The discovery of the oscillatory character of the discharge has largely modified the character of the protection recommended.

EXERCISES.

1. A dynamo is feeding 16 arc lamps that have an average resistance of 4.56 ohms. The internal resistance of the dynamo is 10.55 ohms. The resistance of the line-wire is inconsiderable. What current does the dynamo yield with an E.M.F. of 838.44 volts?
Ans. 10.04 amperes.

2. The current running through the carbon filament of an incandescence lamp was found to be 1 ampere. The difference of potential between the two terminals of the lamp was found to be 30 volts. What was the resistance of the lamp?

3. The resistance of the arc of an electric lamp is 3.8 ohms. The current strength is 10 amperes. What is the difference of potential between the carbon tips? *Ans.* 38 volts.

4. The resistance of the arc lamp above mentioned, when the carbons are held together, is 0.62 ohm. When it is burning with normal arc and a 10-ampere current, what is the difference of potential between the terminals of the lamp? *Ans.* 44.2 volts.

5. Upon trial, it was found that a dynamo that was known to have an internal resistance of 4.58 ohms developed a current of 157.5 volts and 17.5 amperes. What was the resistance of the external circuit?
Ans. 4.42 ohms.

6. Suppose that the armatures of two dynamos rotate at the same speed in fields of like intensity. The armatures differ only in that one has twice as many bobbins in series as the other. How will the dynamos compare in E.M.F.?

7. I have two telegraph sounders. One of them is made with a few turns of coarse wire; the other of many turns of fine wire. Trying them on a long line of great resistance, I find that one works satisfactorily while the other will not work at all. Which sounder works? Explain the difference in the results secured with the two instruments.

8. A telegraph line is to be operated between Boston and Chicago. The high resistance of so long a line requires a current of such high potential that there is great difficulty in maintaining the insulation. How may this difficulty be removed?

V. ELECTROMAGNETIC CHARACTER OF RADIATION.

342. Electromagnetic Waves. — Certain facts well known to physicists suggest with great force that there is some definite relation between electricity and light. It is possible that the characteristic difference is in wave-length.

(*a*) In recent years, Hertz and Tesla have experimented with these electromagnetic waves, and have shown that they may be reflected, refracted, and polarized, and that they possess all the transmittive properties of radiant energy. They have also shown that their velocity is identical with that of light, and that indices of refraction are the same for electromagnetic waves as they are for the shorter waves that are familiarly recognized as radiant energy.

343. The Hertz Experiments. — By methods that cannot be here explained, Hertz, the first successful investigator in this field, was able to determine the periods of the electrical oscillations. To reduce the wave-length to convenient values (say a meter or two), the oscillations were made rapid.

Hertz found that non-conductors are transparent to the electric radiations, and that conductors act as reflectors. He found points of maximum and minimum disturbance corresponding to the loops and nodes of a vibrating string. The wave-lengths thus determined multiplied by the frequency of vibration gave *a velocity for electromagnetic wave propagation that is practically the same as the velocity of light.* Electromagnetic waves, that had passed through floors and walls, have been detected at a distance of hundreds of feet.

344. The Tesla Experiments. — By means of an oscillator in which the armature coils are shot, very rapidly and shuttle-fashion, in and out of the magnetic field, Nikola Tesla generated alternating currents of higher frequency, potential, and regularity than any previously employed.

(*a*) He has shown that such currents flow mostly on the outer surface of the conductor, as though ether vortices were rolled along the wire as a rubber band may be rolled along a pencil. He led a small cable around the walls of a room 40×80 feet in size, and connected its ends to the terminals of an oscillator. In the middle of the room he placed a coil-wound resonator, provided with two adjustable condenser plates. By adjusting the condenser plates, the resonator was so attuned that the frequency of the induced current kept step with that of the cable current. When current from the oscillator was sent along the cable around the room, powerful sparks poured in dense streams across the space between the cymbal-like plates of the attuned condenser in the middle of the room. A potential difference of 200,000 or 300,000 volts is easily developed in this way, and *energy transmitted through free space*, i.e., without any wire.

345. Cathode Rays. — The gaseous molecules that strike the negatively charged electrode of a Crookes tube become electrified and are thrown off. It is supposed that, in the high vacuum of the tube, many of the electrified molecules are actually projected without collision across the tube, striking the glass opposite the cathode. *This stream of electrified particles constitutes the cathode rays.*

(*a*) The particles move in straight lines from the cathode, exert mechanical force, produce heat where they strike, are deflected by a magnet, and produce beautiful phosphorescent and fluorescent effects. Diamonds and rubies glow brightly when subjected to this discharge, and the glass of the tubes fluoresces with a greenish color. The cathode rays of themselves are not luminous, but seem to be intimately connected with light.

346. X Rays. — Roentgen discovered that rays from an excited Crookes tube produced fluorescence even when

opaque substances were interposed between the tube and the fluorescent paper.

(*a*) When he placed his hand between the shielded tube and the paper, he found that the effect penetrated the hand, the flesh offering less resistance than the bones, and thus casting a shadow of the bones upon the paper. He then substituted a photographic plate for the fluorescent paper, and succeeded in photographing the bones of his hand. In experiments of this kind, the prepared photographic plate is placed in an ordinary plate-holder, a light-proof case with a cover of dense pasteboard or thin, hard rubber. The object to be photographed is placed upon this cover as near as possible to the photographic plate, no camera being used. If a hand or arm is to be photographed, a few bandages holding it to the plate-holder avoid movement during the period of exposure, reduce the personal fatigue, and do not interfere with the results obtained; the bandages, plate-holder, etc., are transparent to the X rays. The plate is placed a few inches from the Crookes tube, as shown in Fig. 279, which shows the arrangement of the several parts of the apparatus.

Roentgen showed that the effect apparently proceeds from the tube in straight lines, like rays; that opacity to these rays increases with the thickness of the objects, and usually with their density. These "rays" are invisible to the eye, and do not produce any heat effects; they are incapable of reflection or refraction; they cannot be polarized, and are not deflected by a magnet. They seem to originate where the cathode rays first strike an object. To the unknown cause of this new effect, Roentgen gave the name of "X rays," suggesting, however, that they might be due to longitudinal ether-waves.

347. The Electromagnetic Theory of Light. — Optical and electrical phenomena seem to call for media that have identical properties; i.e., they indicate that the medium of the one is identical with the medium of the other, and that to produce radiation, it is only necessary to produce electric oscillations of sufficiently short period. This theory of light as an electromagnetic disturbance was propounded in 1865 by Maxwell; if recent investigations do not wholly establish it, they certainly give it very strong support.

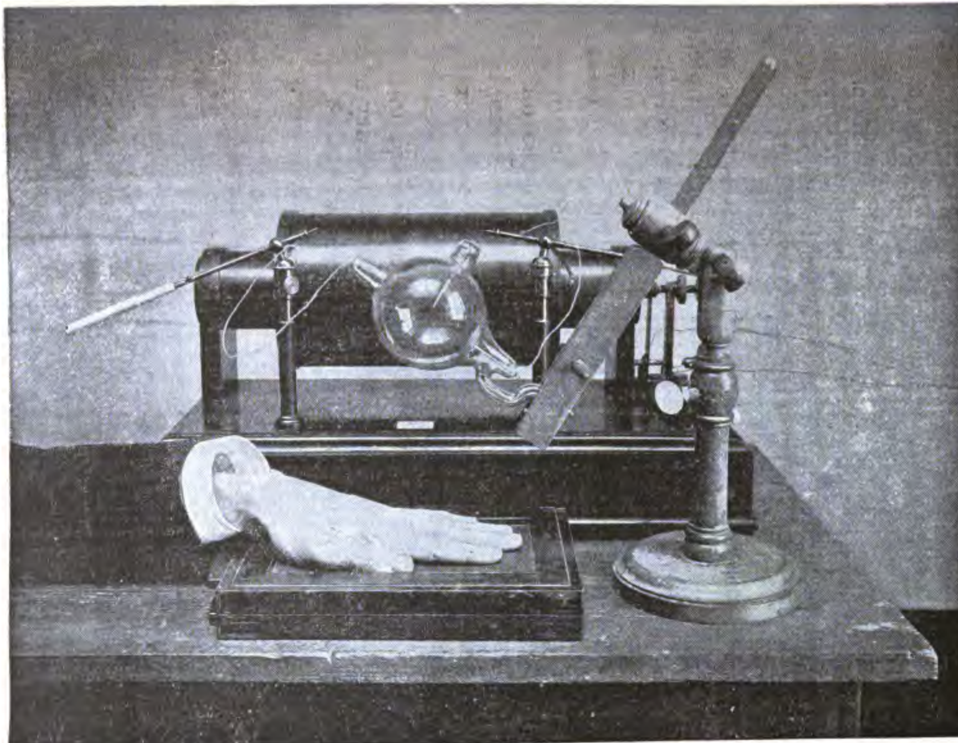

Fig. 279.

(*a*) The theory that electromagnetic waves and light waves differ only in wave-length is winning its way among physicists. The "chasm" between them is growing narrower and narrower; i.e., the length of the shortest electromagnetic wave known does not exceed the length of the longest infra-red wave known as much as it did a few years or months ago. Electromagnetic waves only six millimeters long have already (1897) been produced. The ability to produce and to recognize these "electrical waves" underlies the art of wireless telegraphy, etc.

348. Yesterday, To-day, To-morrow. — It seems fitting to suggest that constant study is the price of a clear understanding of conditions that prevail in the domain of electricity. "Its theoretical problems assume novel phases daily. Its old appliances ceaselessly give way to successors. Its methods of production, distribution, and utilization vary from year to year. Its influence on the times is ever deeper, yet one can never be quite sure into what part of the social or industrial system it is next to thrust a revolutionary force. Its fanciful dreams of yesterday are the magnificent triumphs of to-morrow, and its advance toward domination in the twentieth century is as irresistible as that of steam in the nineteenth."

APPENDIX.

1. Mensurative, etc.

$\pi = 3.14159$.
Circumference of a circle $= \pi D$.
Area of a circle $= \pi R^2$.
Surface of a sphere $= 4\pi R^2 = \pi D^2$.
Volume of a sphere $= \frac{4}{3}\pi R^3 = \frac{1}{6}\pi D^3$.
Meters $\times$ 3.2809 = feet.
Feet $\times$ 0.3048 = meters.
Inches $\times$ 2.54 = centimeters.
Cubic inches $\times$ 16.386 = cubic centimeters.
Cubic centimeters $\times$ 0.06103 = cubic inches.
Kilograms $\times$ 2.2046 = pounds.
Kilogrammeters $\times$ 7.2331 = foot-pounds.

2. Table of Resistivities. — Represent the length of a conducting wire measured in feet by l, its diameter measured in thousandths of an inch (mils) by d, and its resistance measured in ohms by r. In the formula

$$r = \frac{Kl}{d^2},$$

K represents a constant that depends upon the material of the wire and, for the substances considered, is as given in the following table of *resistivities*:—

Silver	9.84	Mercury	58.24
Copper	10.45	Platinum	59.02
Zinc	36.69	Iron	63.35
German-silver	128.29		

These values of K are computed for the temperature of 20°. Thus the resistance of 1,000 feet of No. 0000 copper wire at 20°, is $10.45 \times 1{,}000 \div 460^2 = 0.049 +$ ohms.

x

3. Dimensions and Functions of Copper Wires.—In the table given on the next two pages, the second column gives the diameters in mils, i.e., thousandths of an inch; the third column in millimeters. The fourth column gives the equivalent number of wires each one mil in diameter. By multiplying the numbers in the sixth column by 5.28, the resistances per mile may be found. The resistance for any other metal than copper may be found by multiplying the resistance given in the table by the ratio between the resistivity of copper and that of the given metal (see section 2). The resistances given in the table are for pure copper wire. Ordinary commercial copper wire has a lower conductivity than that of pure copper. Consequently, the resistances of such wires will be greater than those given in the table.

Dimensions and Functions of Copper Wires.

Gauge Number.	Diameter.		Circular Mils.	Sectional Area in Square Inches.	Weight and Length Density = 8.9.		Resistance at 24°.			Capacity in Amperes.
	Mils.	Millim.			Lbs. per 1000 Ft.	Feet per Lb.	Ohms per 1000 Ft.	Feet per Ohm.	Ohms per Lb.	
0000	460.000	11.684	211600.00	0.166190	639.33	1.56	0.051	19929.700	0.0000785	312.
000	409.640	10.405	167805.00	0.131790	507.01	1.97	0.063	15804.900	0.000125	262.
00	364.800	9.266	133079.40	0.104520	402.09	2.49	0.080	12534.200	0.000198	220.
0	324.950	8.254	105592.50	0.082932	319.04	3.13	0.101	9945.300	0.000315	185.
1	289.300	7.348	83694.20	0.065733	252.88	3.95	0.127	7882.800	0.000501	156.
2	257.630	6.544	66373.00	0.052130	200.54	4.99	0.160	6251.400	0.000799	131.
3	229.420	5.827	52634.00	0.041339	159.03	6.29	0.202	4957.300	0.001268	110.
4	204.310	5.189	41742.00	0.032784	126.12	7.93	0.254	3931.600	0.002016	92.3
5	181.940	4.621	33102.00	0.025998	100.01	10.00	0.321	3117.800	0.003206	77.6
6	162.020	4.115	26250.50	0.020617	79.32	12.61	0.404	2472.400	0.005098	65.2
7	144.280	3.665	20816.00	0.016349	62.90	15.90	0.509	1960.600	0.008106	54.8
8	128.490	3.264	16509.00	0.012966	49.88	20.05	0.643	1555.000	0.01289	46.1
9	114.430	2.907	13094.00	0.010284	39.56	25.28	0.811	1233.300	0.02048	38.7
10	101.890	2.588	10381.00	0.0081532	31.57	31.38	1.023	977.800	0.03259	32.5
11	90.742	2.305	8234.00	0.0064670	24.88	40.20	1.289	775.500	0.05181	27.3
12	80.808	2.053	6529.90	0.0051286	19.73	50.69	1.626	615.020	0.08237	23.0
13	71.961	1.828	5178.40	0.0040671	15.65	63.91	2.048	488.250	0.13087	19.3
14	64.084	1.628	4106.80	0.0031469	12.41	80.59	2.585	386.800	0.20830	16.2
15	57.068	1.450	3256.70	0.0025578	9.84	101.63	3.177	306.740	0.33133	13.6
16	50.820	1.291	2582.90	0.0020286	7.81	128.14	4.582	243.250	0.52638	11.5
17	45.257	1.150	2048.20	0.0016086	6.19	161.59	5.183	192.910	0.83744	9.6
18	40.303	1.024	1624.30	0.0012757	4.91	203.76	6.536	152.990	1.3312	8.1

Dimensions and Functions of Copper Wires. — *Continued.*

Gau. Number.	Diameter.		Circular Mils.	Sectional Area in Square Inches.	Weight and Length Density = 8.9.		Resistance at 24°.			Capacity in Amperes.
	Mils.	Millim.			Lbs. per 1000 Ft.	Feet per Lb.	Ohms per 1000 Ft.	Feet per Ohm.	Ohms per Lb.	
19	35.390	0.899	1252.40	0.0009836	3.78	264.26	8.477	117.960	2.2392	6.7
20	31.961	0.812	1021.50	0.0008023	3.09	324.00	10.394	96.210	3.3438	5.7
21	28.462	0.723	810.10	0.0006363	2.45	408.56	13.106	76.300	5.3539	4.8
22	25.347	0.644	642.70	0.0005048	1.94	515.15	16.525	60.510	8.5099	4.0
23	22.571	0.573	509.45	0.0004001	1.54	649.66	20.842	47.980	13.334	3.2
24	20.100	0.511	504.01	0.0003173	1.22	819.21	26.284	38.050	21.524	2.8
25	17.900	0.455	320.40	0.0002516	0.97	1032.96	33.135	30.180	34.298	2.4
26	15.940	0.405	254.01	0.0001995	0.77	1302.61	41.789	23.930	54.410	2.0
27	14.195	0.361	201.50	0.0001583	0.61	1642.55	52.687	18.980	86.657	1.7
28	12.641	0.321	159.79	0.0001255	0.48	2071.22	66.445	15.050	37.283	1.4
29	11.257	0.286	126.72	0.0000995	0.38	2611.82	83.752	11.940	218.104	1.2
30	10.025	0.255	100.50	0.0000789	0.30	3293.97	105.641	9.466	349.805	1.0
31	8.928	0.227	79.71	0.0000626	0.24	4152.22	133.191	7.508	557.286	0.84
32	7.950	0.202	63.20	0.0000496	0.19	5236.66	168.011	5.952	884.267	0.70
33	7.080	0.180	50.13	0.0000394	0.15	6602.71	211.820	4.721	1402.78	0.60
34	6.304	0.160	39.74	0.0000312	0.12	8328.30	267.165	3.743	2207.98	0.50
35	5.614	0.143	31.52	0.0000248	0.10	10501.35	336.810	2.969	3583.12	0.42
36	5.000	0.127	25.00	0.0000196	0.08	13238.83	424.650	2.355	5661.71	0.35
37	4.453	0.113	19.83	0.0000156	0.06	16691.06	535.330	1.868	8922.20	0.27
38	3.965	0.101	15.72	0.0000123	0.05	20854.65	675.220	1.481	15000.50	0.25
39	3.531	0.090	12.47	0.0000098	0.04	26302.23	821.789	1.174	22415.50	0.21
40	3.144	0.080	9.89	0.0000078	0.03	33175.94	1074.110	0.931	35803.80	0.17

4. Table of Natural Tangents.

Arc.	Tangent.	Arc.	Tangent.	Arc.	Tangent.	Arc.	Tangent.
0°	0.000	23°	0.424	46°	1.036	69°	2.61
1	0.017	24	0.445	47	1.07	70	2.75
2	0.035	25	0.466	48	1.11	71	2.90
3	0.052	26	0.488	49	1.15	72	3.08
4	0.070	27	0.510	50	1.19	73	3.27
5	0.087	28	0.532	51	1.23	74	3.49
6	0.105	29	0.554	52	1.28	75	3.73
7	0.123	30	0.577	53	1.33	76	4.01
8	0.141	31	0.601	54	1.38	77	4.33
9	0.158	32	0.625	55	1.43	78	4.70
10	0.176	33	0.649	56	1.48	79	5.14
11	0.194	34	0.675	57	1.54	80	5.67
12	0.213	35	0.700	58	1.60	81	6.31
13	0.231	36	0.727	59	1.66	82	7.12
14	0.249	37	0.754	60	1.73	83	8.14
15	0.268	38	0.781	61	1.80	84	9.51
16	0.287	39	0.810	62	1.88	85	11.43
17	0.306	40	0.839	63	1.96	86	14.30
18	0.325	41	0.869	64	2.05	87	19.08
19	0.344	42	0.900	65	2.14	88	28.64
20	0.364	43	0.933	66	2.25	89	57.29
21	0.384	44	0.966	67	2.36	90	Infinite.
22	0.404	45	1.000	68	2.48		

5. Table of Natural Sines.

Arc.	Sine.	Arc.	Sine.	Arc.	Sine.	Arc.	Sine.
0°	0.000	23°	0.391	46°	0.719	69°	0.934
1	0.017	24	0.407	47	0.731	70	0.940
2	0.035	25	0.423	48	0.743	71	0.946
3	0.052	26	0.438	49	0.755	72	0.951
4	0.070	27	0.454	50	0.766	73	0.956
5	0.087	28	0.469	51	0.777	74	0.961
6	0.105	29	0.485	52	0.788	75	0.966
7	0.122	30	0.500	53	0.799	76	0.970
8	0.139	31	0.515	54	0.809	77	0.974
9	0.156	32	0.530	55	0.819	78	9.978
10	0.174	33	0.545	56	0.829	79	0.982
11	0.191	34	0.559	57	0.839	80	0.985
12	0.208	35	0.574	58	0.848	81	0.988
13	0.225	36	0.588	59	0.857	82	0.990
14	0.242	37	0.602	60	0.866	83	0.993
15	0.259	38	0.616	61	0.875	84	0.995
16	0.276	39	0.629	62	0.883	85	0.996
17	0.292	40	0.643	63	0.891	86	0.998
18	0.309	41	0.656	64	0.899	87	0.999
19	0.326	42	0.669	65	0.906	88	0.999
20	0.342	43	0.682	66	0.914	89	0.999
21	0.358	44	0.695	67	0.921	90	1.000
22	0.375	45	0.707	68	0.927		

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